PRS-CST-91-009
MAY 1991

oreign
roadcast
nformation
ervice

NNIVERSARY
1941 - 1991

JPRS Report

Science & Technology

China
Domestic Communications Satillites

Science & Technology
China
Domestic Communications Satellites

JPRS-CST-91-009 | *8 May 1991*

CONTENTS

Overview of Technological Development and Applications of Communications Satellites

91FE0134A Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 1-7

[Article by Qi Faren [2058 4099 6514] of the Chinese Academy of Space Technology (CAST); MS received 10 July 1989]

[Excerpts]

Abstract

A communications satellite is a combined product of space technology and communications technology. The application of communications satellites is one of the most notable technological achievements. This article gives a review and a brief description of the history and the current status of communications satellites, and presents some views and suggestions on the future development of communications satellites in this country. [passage omitted]

IV. Development of China's Communications Satellite Industry

China was the first developing country that had the capability of developing, launching and operating its own communications satellites. In 1970, China's communications satellite development project was initiated; during 1978-1979, the "Symphony" satellite was used for a series of single and integrated tests which included communications and television transmissions; in 1982, the "Intelsat" was used to conduct a variety of communications tests; during 1982-1984, four analog and digital integrated-services earth stations (the Beijing 13-m station, the Urumqi 15-m station, the Lhasa 13-m station and the Kunming 10-m station) began trial operation; in 1984, China launched its first experimental communications satellite, thus raising the curtain for China's satellite communications industry; in 1986, China's satellite communications industry entered the operational stage by the launch and placing into service of a domestic-coverage communications satellite; in 1988, two additional domestic-coverage satellites were launched. At the present time, China has a total of 12 satellite transponders, which include those purchased or leased from Intelsat and those built by this country. These transponders provide the capability to meet China's current needs in communications and television transmissions.

By the end of 1989, China had placed into operation 300 multi-channel and single-channel-per-carrier (SCPC) telephone circuits, and had constructed 80 earth stations with antennas larger than 5 m, approximately 300 small data stations, and approximately 15,000 satellite television receive-only (TVRO) stations.

As a result of the expanded territories covered by television, communications in remote regions have improved. It is expected that the "Dongfang Hong-3" (DFH-3) communications satellite, after it becomes operational in 1992, will bring satellite communications in this country into a stage of commercialization, and provide relief to China's urgent need for satellite communications by meeting the basic requirements of domestic C-band communications.

Although significant progress has been made in the development of communications satellites over the past few decades, we are still lagging behind developed countries by a wide margin. There are a large number of difficult issues that must be addressed, as outlined below.

(1) Technological gap. Generally speaking, our technologies are still unsophisticated compared with the standards of developed countries; in terms of applications, we are on the same level as other developing countries. We are also behind in single-unit technologies and products; in developing our own products, there is a great deal of work to be done to improve the level of automation, the degree of integration and reliability, and also in cost reduction.

(2) Poor management. There is a lack of coordination between the development of the space segment and the development of the ground segment in satellite communications; also, because of poor system planning, the effective bandwidth is not fully utilized. Even though we have operational satellites and the demand for additional transponders is high, the transponders and effective bandwidth onboard existing satellites are not fully utilized and therefore are being wasted.

(3) Inadequate financial support. Developed countries generally provide stronger financial support for aerospace development both in absolute terms and relative terms. For example, investments by the United States and the Soviet Union exceed 1 percent of their gross national products, with a total of $30 billion. China's investment is two orders of magnitude lower than that of the two superpowers, and one order of magnitude lower than that of Western Europe and Japan. Because of its limited financial resources, China cannot allocate funds for aerospace development comparable to those of developed countries; consequently, certain constraints must be imposed on the development and application of communications satellites.

Recently, China has announced the launch by 1992 of a medium-capacity communications satellite, the "DFH-3," to be used for domestic communications and television broadcasts. It is equipped with 24 standard-bandwidth transponders whose effective isotropic radiated power (EIRP) will be greater than 34 dBW and 37 dBW; it has a total radiated power of 240 W and a design life of more than 8 years. The satellite employs frequency-reuse [or frequency-division multiplexing (FDM)] technology with orthogonal-polarization separation and dual-grid high tower communications antennas; the equipment compartment will have a modularized structure made of light-weight composite materials. It

also uses many new technologies such as a three-axis stabilized attitude control system, bi-constituent integrated propulsion [i.e, bipropellant] system, and large-area fine-mesh-grid solar panels. The application of these technologies will raise the standard of China's satellite technology to the state-of-the-art level as of the early 1980's.

The "DFH-3" satellite will also be the first society-oriented, commercially-operated communications satellite in this country. The 24 transponders can simultaneously transmit six channels of color television programs and 15,000 channels of telephone, telegraph, facsimile and data signals. A second such satellite, designated "DFH-3D," is expected to be launched shortly afterwards and will be stationed at a different orbital position; thus the total communications capacity and the range of applications will both increase significantly.

Of course, to meet society's future needs, higher-level and longer-range development plans are also being considered. For example, the use of new communications bands such as the Ku, L, and UHF bands is being studied; advanced communications techniques, dedicated communications satellites and mobile communications satellites are being developed; the number of transponders will be further increased to provide additional voice channels for the public. In addition, fiber-optic communications and microwave communications will be developed in conjunction with satellite communications to provide complementary communications capabilities.

Space technology has been designated as one of China's high-priority technologies, and being an important branch of space technology, communications technology is expected to grow rapidly in the future. In order to maintain China's momentum in satellite development and to accomplish the difficult tasks ahead of us, it is suggested that we should concentrate on the following areas:

(1) Management and coordination. The design of a satellite communications system is a complex systems engineering effort which involves a wide range of disciplines, and must take into consideration many different factors in its overall planning. Therefore, it is important to establish a strong management system to provide complete coordination and cooperation, and to avoid bureaucratic waste, duplication of development efforts and misuse of investments.

(2) Personnel. It is important to maintain a relatively stable technical staff and to build a team of highly motivated, technically competent and disciplined personnel with different experience levels. Special effort should be made to adjust and strengthen the existing teams and to provide good working and living conditions to stimulate professional growth.

(3) Research and development. R&D activities in basic technologies and materials should be enhanced to improve component performance. In particular, coordinated efforts should be organized to develop our own capability in manufacturing certain key components; to accomplish this, some of the existing equipment must be replaced or modified.

(4) New technologies. Emphasis should be placed on preliminary research of certain key payload technologies and on building a solid foundation for China's communications satellite industry in order to catch up with the developed countries. These include Ku-band technology, variable-beamwidth antennas, multiple-beam and large-aperture spacenet antennas, onboard switching technology, etc. At the same time, additional laboratories and test facilities should be constructed.

(5) International cooperation and the overseas market. Cooperative projects with foreign countries should be encouraged in order to fully take advantage of other countries' achievements and experience. Also, because of the rapidly growing satellite communications market around the world, an organized effort should be made to conduct market surveys and to expand China's market share. Situated on the Asian continent, we are in a very competitive position because there are many developing countries in Asia which do not have the capability to develop and launch their own satellites, and because our launch costs and development costs are relatively low. Furthermore, with the increasing number of satellites being launched into orbit, the demand for ground receiving stations is likely to grow; for example, after the launch of the "Asia Sat-1" satellite, there has been increased demand for C-band communications earth stations from Southeast Asian countries such as Pakistan, Thailand, Burma and the Philippines.

(6) Domestic market. Emphasis should also be given to promotional efforts for the purpose of expanding the applications of communications satellites to meet the needs of the domestic market. The general public should be educated so they are able to understand and to fully exploit the benefits of utilizing communications satellites. The increased number of ground stations will drive down the cost of ground facilities.

Currently, many provincial government offices and businesses around the country are promoting the use of dedicated satellite communications networks, thus creating a potentially vast domestic market.

In conclusion, the current status of China's communications satellite technology can be summarized as follows: We have made significant progress over the past few decades and our future appears promising; however, technologically, we are still far behind developed countries, and many difficult problems still remain.

Technical Requirements of Communications Satellites

91FE0134B Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 8-13

[Article by Min Shiquan [7036 1102 2938] of the China Broadcasting Satellite Corporation; MS received 15 August 1989]

[Excerpts]

Abstract

This article presents 15 key factors that should be considered in establishing technical requirements for communications satellites. The relationships between these factors and the technical requirements are illustrated using a domestic commercial satellite as an example. [passage omitted] Establishing technical requirements for communications satellites is a highly technical and difficult task. This article presents 15 key factors that should be considered in order to achieve the qualities of completeness, correctness and feasibility in a comprehensive set of technical requirements.

1) Transmission Capacity. The transmission capacity of a communications satellite refers to the number of voice channels that can be transmitted by the satellite for a given communications network and ground-station configuration. The parameters which affect the transmission capacity, e.g., the number of transponder channels, channel bandwidth, and effective isotropic radiated power (EIRP), are determined based on satellite communications requirements.

2) Transmission Quality. The transmission quality of a communications satellite is primarily determined by the performance of the onboard antennas and transponders in receiving and transmitting signals and noise. The factors which affect signal transmission quality should be carefully analyzed to establish constraining requirements on them. In addition, the quality issue of onboard radio telemetry, tracking and control (TT&C) equipment should also be addressed.

3) Service Area. The service area depends on the coverage area of the receiving and transmitting beams of the satellite. The requirements on beam characteristics and satellite position are established based on the geographic location of the service area and the voltage distribution within the area as required by the satellite communications system.

4) Service Time. Service time refers to the length of time over which satellite transponders can maintain communications with the earth station. Geostationary satellites are generally powered by solar cells; however, at the beginning of the spring and fall season each year, they are in earth shadow (lasting approximately 45 days before and after the spring and fall equinox with the longest duration of 72 minutes per day). During this so-called eclipse period, solar cells cannot function; therefore, in order to ensure continuous operation of the transponders, power must be provided by batteries onboard the satellite. The operational requirements for the transponders during the eclipse period should be established on the basis of need and feasibility.

5) Consistency. The onboard radio equipment must be consistent with the ground equipment (e.g., radio frequency) in order to ensure that all performance parameters of the communications channels meet design requirements.

6) Interference Rejection. Based on the specific satellite application, interference-rejection requirements must be established for the onboard communications and TT&C equipment. For military satellites, it is also necessary to consider survivability in electronic countermeasures (ECM) situations or electronic warfare (EW).

7) Service Life and Reliability. Requirements for on-orbit service life and reliability are determined in accordance with the satellite orbit design and the replacement strategy in case of failure.

8) Flexibility. In order to accommodate changes in the modes of communication, the satellite design must provide sufficient flexibility in terms of orbit position, beam pointing and connectivity between the transponders and the antenna beams.

9) Compatibility. There must be compatibility between the mechanical interfaces of the satellite and the launch vehicle; there must also be electromagnetic compatibility between all the onboard equipment and between the satellite and the launch vehicle, the launch-site equipment, and the ground TT&C network.

10) Comprehensive Utilization. In order to make efficient use of the radio-frequency (RF) resources and to reduce satellite weight and power consumption, the satellite design should take into consideration the comprehensive utilization of channels for onboard communications and TT&C systems.

11) Design Constraints. Strict design constraints should be imposed on satellite performance in order to avoid interference with the operation of neighboring satellite communications systems. For example, constraints should be established for satellite positioning accuracy, beam-pointing accuracy and sidelobe characteristics.

12) Manageability. In order to ensure that the ground TT&C stations and communications monitoring stations can satisfactorily perform the functions of measurement, control and management of satellite operations, requirements should be established for the onboard telemetry, remote control and tracking systems in accordance with the on-orbit operations plan and the ground-station configuration.

13) Recoverability. If component failures are encountered during the launch phase or the operational phase, provisions must be made for the satellite to recover or to restore its design capabilities (including the use of

ground control or other means to replace the failed parts by back-up units). Requirements should be established based on the expected failure rates and the recovery strategies.

14) Survivability. This refers to the ability of military satellites to defend against destructive attempts by adversaries.

15) Security. For military satellites, the onboard radio equipment must be protected by security measures against information leaks or sabotage.

On the basis of the above key factors, illustrative technical requirements for a domestic commercial satellite are presented in the following table. The last column of the table labeled "Attribute" refers to the particular key factor from which the requirement is derived.

These requirements primarily relate to the communications subsystem and the radio TT&C subsystem of the satellite; to a lesser degree they also relate to the attitude- and orbit-control subsystem and the overall satellite system.

Table 1. Illustrative Technical Requirements for a Domestic Commercial Communications Satellite

Requirement No.	System category	Name	Typical value	Attribute
1	Communications subsystem	Transponder type	Microwave transponder with single frequency conversion	5
2	"	Operating frequency range	Receive band 5925-6425 MHz; transmit band 3700-4200 MHz	5
3	"	Number of transmission channels	24	1
4	"	Number of operating channels during eclipse	24	4
5	"	Channel operating bandwidth	36 MHz	1
6	"	Guardband bandwidth	4 MHz	1, 2
7	"	Center frequency of receive channel	5925 + 20 n MHz, n = 1, 2, ..., 24	5
8	"	Center frequency of transmit channel	3700 + 20 n MHz, n = 1, 2, ..., 24	5
9	"	Receive antenna type	Shaped-single-beam coverage	1,11
10	"	Receive coverage area	The entire Chinese territory	3
11	"	Gain slope inside the receive coverage area	Less than 5 dB/deg for any 0.4 deg chord segment	3
12	"	Sidelobe characteristics outside the receive coverage area	24 dB below the maximum gain inside the coverage area	11
13	"	Polarization characteristics inside the receive coverage area	Vertical polarization for odd-number channels, horizontal polarization for even-number channels	5
14	"	Isolation between orthogonal polarizations inside the receive coverage area	Greater than 33 dB	2
15	"	Quality factor inside the receive coverage area	Greater than -4 dB/K	1, 2
16	"	Saturation flux density (the top-grade gain)	-86 +/- 1 dBW/m^2	2
17	"	Channel gain adjustment characteristics	Successive reduction from the top-grade gain by 2, 4, 6, 8, 10 dB	8
18	"	Transmit antenna type	Shaped-single-beam coverage	1,11
19	"	Transmit coverage area	The entire Chinese territory	3
20	"	Gain slope inside the transmit coverage area	Less than 5 dB/deg for any 0.4 deg chord segment	3
21	"	Sidelobe characteristics outside the transmit coverage area	24 dB below the maximum gain inside the coverage area	11
22	"	Polarization characteristics inside the transmit coverage area	Horizontal polarization for odd-number channels, vertical polarization for even-number channels	5
23	"	Isolation between orthogonal polarizations inside the transmit coverage area	Greater than 33 dB	2
24	"	EIRP at the edge of the transmit coverage area	Greater than 36 dBW under single-carrier saturation condition	1
25	"	Range of EIRP	0.5 dB peak-to-peak/day; 1 dB peak-to-peak/lifetime	2
26	"	Clutter radiated power inside the 3670-4230 MHz band	Lower than -30 dBW in any 4 KHz band; lower than -25 dBW in a 1 MHz band	2

27	"	Clutter radiated power outside the 3670-4230 MHz band	Lower than -30 dBW in any 4 KHz band	11
28	"	Transponder frequency conversion accuracy	Less than +/-1x10^{-5} during lifetime (including initial error and the effect of earth shadow)	2
29	"	Short-term frequency stability	Noise and parasitic frequency modulation not to exceed 105 Hz RMS within the 100 Hz-12 KHz band	2
30	"	Gain stability	1 dB/day; 3 dB/lifetime	2
31	"	Channel super-saturation capability	20 dB overload for 24 hours acceptable	6, 7
32	"	Gain flatness within the channel band	Peak-to-peak effective radiated power (ERP) in the transmission band less than 1 dB	2
33	"	Gain slope within the channel band	ERP at any point within the transmission band less than 1 dB/MHz	2
34	"	Suppression outside the channel band	Respective attenuations corresponding to +/-20, +/-25, +/-30 MHz from the channel center frequency are greater than 20, 40, 60 dB	2, 6
35	"	Suppression outside the wideband receive band	Respective attenuations corresponding to 160, 200 MHz outside the 5925-6425 MHz band are greater than 20, 25 dB; the attenuation corresponding to input frequencies inside the 3700-4200 MHz band is greater than 55 dB	2, 6,11
36	"	Total group delay inside the channel band	Respective group delays corresponding to +/-4, +/-8, +/-12, +/-16, +/-18 MHz from the channel center frequency are 0-4, 2-8, 7-21, 20-45, 35-80 nanoseconds (ns)	2
37	"	Group-delay ripple inside the channel band	Peak-to-peak values less than 3 ns/10 MHz	2
38	"	Group-delay stability inside the channel band	Less than +/-2 ns	2
39	"	Amplitude linearity	For input constant-amplitude double-carriers which are 3, 6, 14 dB lower than the single-carrier saturation flux density, the 3rd-order inter-modulation product is 10, 16, 27 dB lower than the corresponding carrier voltage	2
40	"	Total channel phase shift	Respective maximum phase shifts corresponding to single-carrier saturation flux densities of 0, 3, 6, 9, 12, 15 dB are less than 46, 38, 28, 18, 12, 9 degrees	2
41	"	Amplitude and phase modulation conversion coefficient	Respective amplitude and phase modulation conversion coefficients corresponding to the single-carrier saturation flux densities of 0, 3, 6, 9, 12, 15 dB are 8, 8, 8, 7, 5, 4 deg/dB	2
42	"	Frequency modulation (FM) modulation-conversion characteristics	Intelligible cross-talk in single transmission channel less than -58 dB	2
43	"	Communication interrupt time due to channel switching	Less than 25 ms	4
44	Radio telemetry and control subsystem	Radio telemetry and control configuration	Uplink carrier shared by remote-control and uplink ranging signals; downlink carrier shared by telemetry and downlink ranging signals	10
45	"	Telemetry and control frequency range and polarization	Same as communications band; receive: horizontal polarization in the 5925-5943 MHz band, vertical polarization in the 6407-6425 MHz band; transmit: vertical polarization in the 3700-3718 MHz band, horizontal polarization in the 4182-4200 MHz band	5,10
46	"	Isolation between orthogonal polarizations	Greater than 33 dB for both receive and transmit	2
47	"	Number of pieces of telemetry and control equipment	Two sets of telemetry and remote-control ranging equipment which are cross-connected and serve as back-up to each other	7,13
48	"	Receive antenna type	Same omnidirectional antenna used before and after final orbit injection	7,13

49	"	Receive frequency	Two fixed-frequency points selected from a given frequency range	5
50	"	Receive carrier modulation configuration	Carrier FM by means of remote-control and ranging signals	5
51	"	Modulation index	Peak frequency deviation +/-400 KHz	5
52	"	Receive signal flux density	Greater than -90 dBW/m^2 before and after final orbit injection	5
53	"	Receiver dynamic range	Greater than 45 dB	5
54	"	Local oscillator frequency stability	Better than $+/-2x10^{-5}$	2
55	"	Receiver bandwidth	1.0-1.5 MHz	5
56	"	Receiver over-excitation ability	17 dB higher than the upper limit of dynamic range	6, 7
57	"	Transmitting antenna type	Omnidirectional antenna before final orbit injection; directional antenna or shared communications antenna after final orbit injection	5
58	"	Transmit frequency	Two fixed-frequency points selected from a given frequency range	5
59	"	Transmit carrier modulation configuration	Phase modulation of carrier by means of telemetry and ranging signals	5
60	"	Modulation index	Ranging format: 1.0+/-0.13 rad; telemetry format: 1.0+/-0.05 rad	5
61	"	EIRP of transmit signal	Greater than 0 dBW inside the satellite coverage area before/after orbit fixing	5
62	"	Parasitic output of transmit signal	Total output 40 dB lower than the carrier; output within the transmit bandwidth 62 dB lower than the carrier	2,11
63	"	Transmit frequency stability	Better than $+/-1x10^{-5}$	2
64	"	Ranging system	Pure-tone ranging at four single tones (283.4, 3968, 19000, 27777 Hz)	5
65	"	Ranging accuracy of onboard equipment	Less than 20 m	2
66	"	Remote-control sub-carrier modulation system	PCM/FSK modulation of sub-carrier using a 3-tone baseband formed by "1," "0," and continuous tone for data execution	5
67	"	Sub-carrier frequency	Four tones selected from 5-27 KHz band	5
68	"	Bit rate	100 bits/s	5
69	"	Instruction-code bit error rate (BER)	Less than $1x10^{-5}$	2
70	"	Instruction-code format	Total 58 bits; synchronization, reset, address, command word, and command preamble occupy respectively 16, 16, 10, 10 and 6 bits	5
71	"	Probability of missed command	Less than $1x10^{-6}$	7
72	"	Probability of crossed command	Less than $1x10^{-9}$	7
73	"	Mode of verification of command transmission	Verification by telemetry with ground command	12
74	"	Telemetry sub-carrier modulation configuration	PCM/PSK	5
75	"	Sub-carrier frequency	32 KHz	5
76	"	Sub-carrier frequency stability	Better than $+/-2x10^{-6}$	2
77	"	Bit rate	1000 bits/s	5
78	"	Bit-rate stability	Better than $+/-2x10^{-6}$	2
79	"	BER	Better than $1x10^{-4}$	2
80	"	Digitization accuracy	+/-0.5 percent of full range	2
81	"	Telemetry signal identifiers	Identifiers required for satellite, main frame, sub-frame, etc.	12
82	"	Main-frame cycle	0.512s	5
83	"	Number of words in main frame	64	5

84	"	Sub-frame cycle	4.096s (8 channels), 8.192s (16 channels), 16.384s (32 channels)	5
85	"	Telemetry output signal format	Non-return-to-zero modulated serial code, 8 bits/word with most significant bit first	5
86	Attitude- and orbit-control subsystem	Satellite position	125 deg east longitude	3
87	"	Station-keeping accuracy	Less than +/-0.1 deg in both east-west and north-south directions	11
88	"	Re-positioning capability	One-time re-positioning capability provided by auxiliary propellant to initiate or eliminate 1 deg/day east-west drift	8
89	"	Beam-pointing accuracy	For three-axis stabilized satellite, less than +/-0.15 deg in pitch and roll directions, less than +/-0.5 deg in yaw direction	3,11
90	"	Offset beam-pointing capability	Short-term pitch and roll +/-4.0 deg, long-term pitch +/-2.0 deg, roll +/-0.2 deg	8
91	Overall system	Electromagnetic compatibility during launch and deployment	Satellite should be electromagnetically compatible with the launch vehicle, the launch-site equipment and the TT&C network	9
92	"	Electromagnetic compatibility during satellite operation	All measurement, control and communications equipment must be free from mutual interference	9
93	"	Service life	Longer than 8 years	7
94	"	Reliability	At end of life, the probability of having at least 20 of the 24 transponder channels functioning continuously should be greater than 0.80	7

References

1. Ford Aerospace Corporation: INTELSAT V, National Defense Industry Publishing House, July 1982.

Technical Summary of Communications Satellites

91FE0134C Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 14-20

[Article by Li Ye [2621 8528] of the Beijing Institute of Spacecraft Systems Engineering; MS received 20 August 1989]

[Excerpts]

Abstract

This article presents a technical summary of communications satellites. Specifically, constraint conditions in the design of communications satellites are illustrated, and major design issues for the payload subsystem, the attitude- and orbit-control subsystem, the power-supply subsystem, and the telemetry, tracking and control (TT&C) subsystem are discussed. [passage omitted]

I. Considerations of Constraint Conditions on System Interface

[Passage omitted] China's first- and second-generation communications satellites were launched by Long March 3 boosters; these rockets not only had a high launch-success rate, but also had very high guidance accuracy. The third-generation high-capacity communications satellites are expected to be launched by the modified Long March 3—the Long March 3A booster; however, they are also designed to be launch-compatible with the Ariane rocket.

China's Xichang Launch Center is an ideal launch site for geosynchronous satellites. Because it is located at a relatively low latitude, a satellite can be launched into a low-inclination orbit, which minimizes the energy required for changing the orbit plane. Compared with the Soviet launch site Baikonur, the energy required for orbit change is reduced by 15-20 percent.

II. Payload Design

[Passage omitted]

1. Selection of Frequency Range

[Passage omitted] The satellites that currently exist or are under development in this country all operate at C-band. At the same time, we are also developing K-band transponders in preparation for the next-generation communications satellites.

2. Frequency Division Multiplexing (FDM) and New Antennas

[Passage omitted] China's satellites from the previous two generations did not require FDM because they were equipped with only a small number of transponders. But the DFH-3 satellite must use polarization isolation in order to accommodate 24 transponders in a 500 MHz band.

The continuous improvement in antenna performance and antenna structure has resulted in enhancement in the overall performance of communications satellites. The early communications antennas were mostly omnidirectional antennas; later, directional antennas and multiple-feed shaped-beam antennas were developed which raised the antenna gain by a factor of 6-8. The antennas used on China's first-generation satellites were global-coverage antennas with an antenna gain of only 14 dB. The second-generation satellites used single elliptic-beam antennas which covered the entire Chinese territory and had a gain of 23 dB. The third-generation antennas are multiple-feed shaped-beam antennas with a gain of 27 dB and a diameter of 2 m; they are also expandable for ease of storage inside the fairing of the launch vehicle.

3. Selection of the Final-Stage Power Amplifier

The early satellites all used traveling-wave-tube amplifiers (TWTA's) as the final-stage amplifier; however, in the 1980's, they were replaced by solid-state power amplifiers (SSPA's) when gallium arsenide field-effect tubes became available. Although the SSPA has only one-half the conversion efficiency of the TWTA, it is the preferred low-power amplification device because of its light weight, good linearity, stable performance and long service life.

China's first-generation satellites used exclusively TWTA's; the second- and third-generation satellites use a combination of TWTA's and SSPA's. [Passage omitted]

IV. Propulsion System Technology

[Passage omitted] China's early communications satellites were dual spin-stabilized, and used solid propellant with added single-constituent hydrazine; the antenna-pointing accuracy was only 0.6 deg. The third-generation satellite will be three-axis stabilized and use a liquid bipropellant; its antenna-pointing accuracy is expected to be less than 0.15 deg in pitch and roll and less than 0.5 deg in yaw.

V. Power Supply System Technology

[Passage omitted]

1. Solar Cells

[Passage omitted] China's first-generation communications satellites used ordinary solar cells with a conversion efficiency around 10 percent; the second-generation satellites used improved ordinary solar cells with a conversion efficiency of 11 percent; the third-generation satellites will use shallow-junction, fine-mesh, back-reflector-type solar cells with a conversion efficiency of 12 percent.

2. Batteries

[Passage omitted] All of China's communications satellites used (or will use) nickel-cadmium batteries; on some dedicated communications satellites hydrogen-nickel batteries are also used.

3. Solar Panels

[Passage omitted] On China's third-generation communications satellites, rigid solar panels imported from abroad will be used. [Passage omitted]

VII. Telemetry, Tracking and Control System and Technology

[Passage omitted] China's communications satellites all use C-band as the TT&C frequency range. The first- and second-generation satellites used phase modulation (PM) and FM for the uplink carrier and PM for the downlink carrier. The third-generation satellites use only FM for the uplink and PM for the downlink. [passage omitted]

References

1. R. C. Collette and B. L. Herdan, "Design Problems of Spacecraft for Communication Missions," IEEE, Vol 65, No 3, 1977, March.

2. James Martin, "Communications Satellite Systems," 1980.

3. K. Miya, "Satellite Communications Technology."

4. "Long March 3 User's Manual, 1985."

5. "Long March 3-A User's Manual, 1989."

6. "INTELSAT V," National Defense Industry Publishing House.

7. "INTELSAT IV," National Defense Industry Publishing House.

8. FOREIGN MISSILES AND ASTRONAUTICS, May 1981.

9. "Aerospace Industry in Modern China," China Social Science Publishing House.

10. "Functional Communications Satellites," Astronautics Publishing House, 1987.

11. "Satellite Communications Engineering," National Defense Industry Publishing House.

12. P. Kumar, "Thermal Design of the Communications Technology Satellite."

Two Different Attitude-Control Methods for Geosynchronous Communications and Broadcasting Satellites

91FE0134D Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 28-35

[Article by Lu Zhenduo [0712 2182 6995] of the Beijing Institute of Control Engineering; MS received 29 September 1989]

[Excerpts]

Abstract

In this article, two attitude-control methods for geosynchronous satellites are discussed: attitude control by satellite-ground loop and autonomous onboard attitude control.

The attitude control of the Chinese-built satellites STW-1 and STW-2 is described, and the development of a dual-spin attitude-control system for future satellites is outlined. Some design issues of the attitude-control system for three-axis-stabilized satellites currently under development in this country are also discussed. [passage omitted]

II. Satellite-Ground-Loop Attitude Control

[Passage omitted]

2. Satellite-Ground-Loop Attitude Control for a Spin-Stabilized Satellite

The attitude control of a spin-stabilized satellite is the control of the satellite spin direction. The so-called satellite-ground-loop attitude-control system consists of the telemetry and control system, the ground computer and the synchronous controller; control of the satellite is accomplished by ground command, which activates the thruster (monopropellant or bipropellant) along the axial direction of the satellite. This type of control is used on the STW-1 and STW-2 satellites. The thrust engine operates in a pulsed mode, where jet firings occur once every spin cycle. [passage omitted]

III. Onboard Autonomous Attitude-Control System

1. Autonomous Attitude Control for Spin-Stabilized Satellite

[Passage omitted]

The functions provided by the attitude-control processing circuit are:

(1) Processing of attitude data;
(2) Platform de-spin control;
(3) Control of antenna pointing mechanism;
(4) Thruster and nutation control (TANC);
(5) De-spin active nutation damping (DAND);
(6) Attitude control-thruster interface circuit;
(7) Spinner speed control;
(8) Fault identification and safety circuit;
(9) Telemetry and remote-control interface circuit.

The above control method will also be used by the full-orbit slender-body dual-spin attitude-control system currently being developed domestically (see Figure 4).

In order to provide improved reliability for the onboard autonomous attitude-control system, it is necessary to consider the satellite-ground loop as a back-up.

2. Autonomous Attitude Control for a Three-Axis-Stabilized Satellite

A three-axis-stabilized satellite can use two different methods of stabilization: one method consists of spin stabilization during the transfer orbit and three-axis stabilization in geosynchronous orbit, and the other method consists of all three-axis stabilization; the latter is the method developed for future attitude-control systems. This type of system is a closed-loop system for onboard autonomous control. In general, the transfer from one mode of operation to another is accomplished automatically; the ground station provides merely a monitoring function. The major operational modes include: sun acquisition, Earth acquisition, attitude stabilization after fourth-stage ignition, station keeping, etc.

Since these satellites are designed for high-capacity communications and broadcasting, they generally have large solar panels and antennas, and often carry an amount of liquid fuel more than half the lift-off weight. As a result, the dynamics of satellite motion become very complicated; one must consider not only the disturbances caused by the appendages, but also the sloshing of liquid inside the fuel tank. This presents considerable difficulties for the attitude-control system. This type of control system will be used by the three-axis-stabilized communications and broadcasting satellite currently being developed by this country. [passage omitted]

The stability analysis of a non-linear satellite control system is based on the Nyquist diagram or amplitude-phase diagram, which is constructed using the method of descriptive functions.

Experience shows that the amplitude-phase diagram can be divided into three stability regions:

a) Phase-lead stability region, in which there is adequate stability reserve between the phase angles -180° and +180°, and the gain is greater than 0 dB;

b) Phase-lag stability region, in which there is adequate stability reserve between the phase angle -540° and -180°, and the gain is greater than 0 dB;

c) Gain stability region, in which the gain is less than 0 dB and there is no condition on phase.

In system analysis and design, one must consider the coupling effect between the system control frequency derived from rigid-body analysis and the first modal frequencies of the flexible solar panel and the sloshing

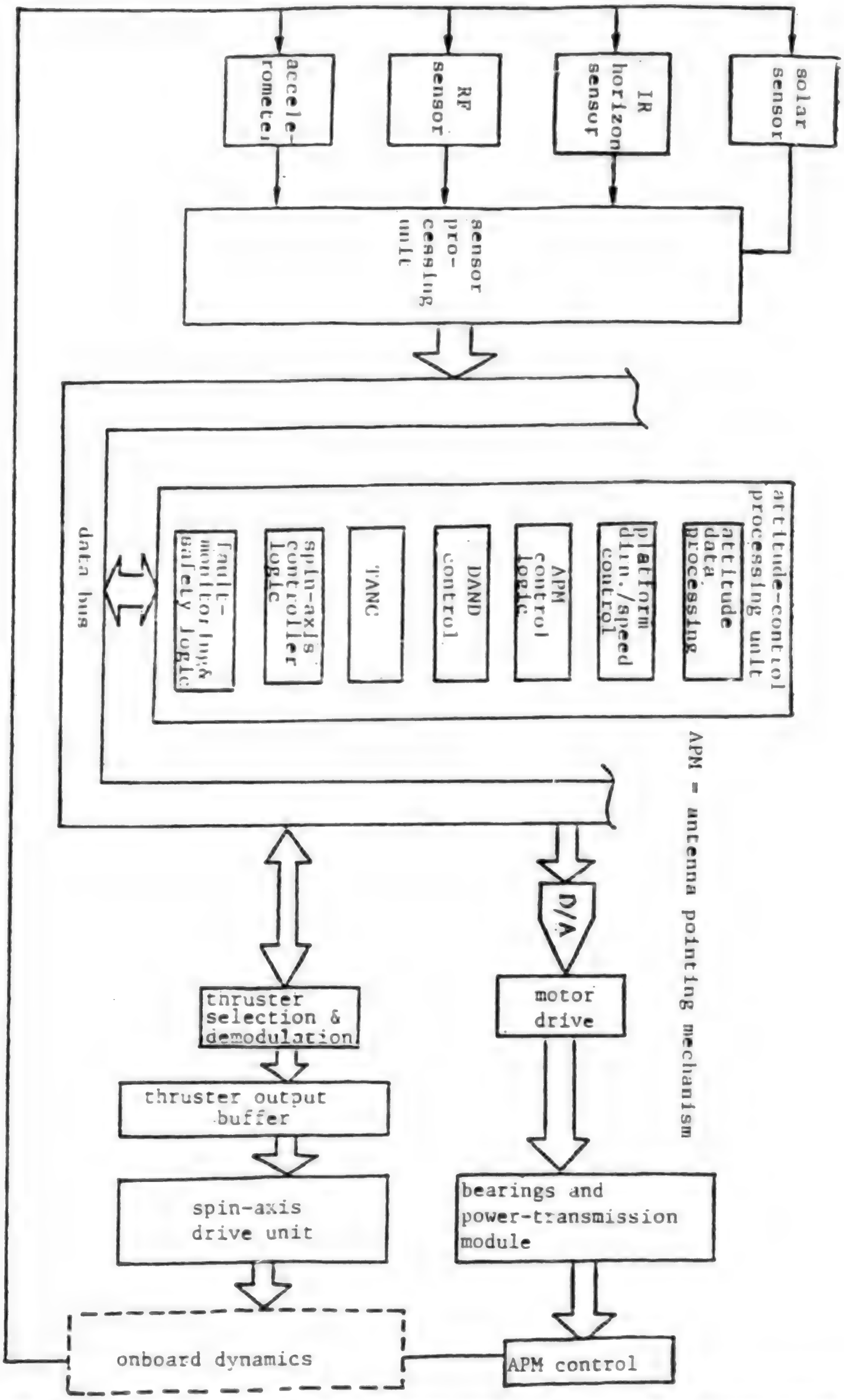

Figure 4. Flow Chart of Autonomous Attitude Control for Geosynchronous-Orbit Slender-Body Dual-Spin-Stabilized Satellite

motion inside the fuel tank. A correction circuit should be implemented to isolate the system control frequency from the modal frequencies in order to improve the dynamic stability of the system.

Finally, the stability and performance indices of the satellite control system should be determined by real-time mathematical simulations and hybrid simulations.

A typical control circuit is shown in Figure 6.

References

1. Tu Shandeng, Lu Zhenduo, Zou Guangrui, Xing Guangqian, Liu Liangdong, "Control of the Chinese Geosynchronous Experimental Communications Satellite STW-1," YUHANG XUEBAO [JOURNAL OF THE CHINESE SOCIETY OF ASTRONAUTICS], No 4, 1986.

Optimal Strategy for Inclination Control of Geostationary Satellites

91FE0134E Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 36-44

[Article by Li Tieshou [2621 6993 1108] of the Beijing Institute of Control Engineering; MS received 7 August 89]

[Excerpts]

Abstract

In this article, the inclination vector is used as a non-singular orbit element to establish engineering-oriented mathematical models for orbital inclination control of geostationary satellites. On the basis of these models, an optimal fuel strategy for inclination control has been derived for both north-south station acquisition and north-south station-keeping. The results of this paper can be applied to missions requiring north-south station-keeping accuracies of 0.05° to 0.1°; they have been implemented in the flight control of the Chinese communications and broadcasting satellite, STW-2.

I. Introduction

The nominal orbit of a geostationary satellite is a 24-hour circular orbit in the equatorial plane. Any deviation of the orbit plane from the equatorial plane will cause the satellite to move in a figure "8" pattern relative to the Earth with a period of one day. A large deviation will make it difficult for the ground antenna to track the satellite. Therefore, it is required to control the orbit inclination of a modern communications satellite to an accuracy of 0.05° to 0.1°.

Deviations of the orbit plane are primarily caused by: 1) residual orbit-injection error introduced by the launch vehicle and the apogee motor; 2) orbit perturbations due to solar and lunar gravitational forces. Correction of the first type of inclination error is called north-south station acquisition, and periodic correction of the second type of error is called north-south station-keeping. In general, the fuel consumption for inclination control is more than 90 percent of the total fuel consumption for attitude and orbit control after injection. Therefore, an optimal strategy for inclination control is important from the standpoint of efficient use of fuel and prolonging satellite service life.

The problem of inclination perturbation and control strategy has been addressed in many papers in the literature.[1] Ref. 2 presented several methods of computing the optimal initial ascending nodes for passive inclination control (commonly referred to as the "negative bias" inclination control). Ref. 3 discussed several optimal guidelines for long-term station-keeping, but it failed to derive the corresponding control strategies and computational methods. In this article, a simplified model of inclination vector control and a perturbation model have been developed; these models are used to derive a universal optimal strategy for north-south station acquisition and north-south station-keeping. The results of this paper have been successfully applied to the flight control of the Chinese communications and broadcasting satellite STW-2.[4] [passage omitted]

VIII. Conclusion

Motivated by engineering applications, we have used the inclination vector as a non-singular orbit element to establish a control model, as in equation (3), and a perturbation model, as in equation (7). On the basis of these models, a universal optimal fuel strategy has been derived for the inclination control of both north-south station acquisition and north-south station-keeping, as represented by equations (12)-(14). The above results can be applied to missions which require inclination control accuracies of 0.05° to 0.1°.

In closing, the author wishes to express his thanks to research engineers Tu Shandeng, Lu Zhenduo, and Comrade Liu Liangdong for their valuable guidance and assistance in this work.

References

1. Zhang Renwei, "Orbit and Attitude Control of Geostationary Satellites," Beijing, Science Publishing House 1987, Chapter 2.

2. A. Kamel and R. Tibbitts, "Some Useful Results on Initial Node Locations for Near-Equatorial Circular Satellite Orbits," CELESTIAL MECHANICS, Vol 8, pp 45-73, 1973.

3. E. Mattias Soop, "Introduction to Geostationary Orbits," ESA SP-1053, November 1983, Chapter 6.

4. Lu Zhenduo, Li Tieshou, and Liu Liangdong, "Improvements in Attitude- and Orbit-Control Software for Chinese STW-2 Satellite," Proc. of Pacific Basin International Symposium on Advances in Space Science Technology and Its Applications, Beijing, China, June 1987, pp 611-618.

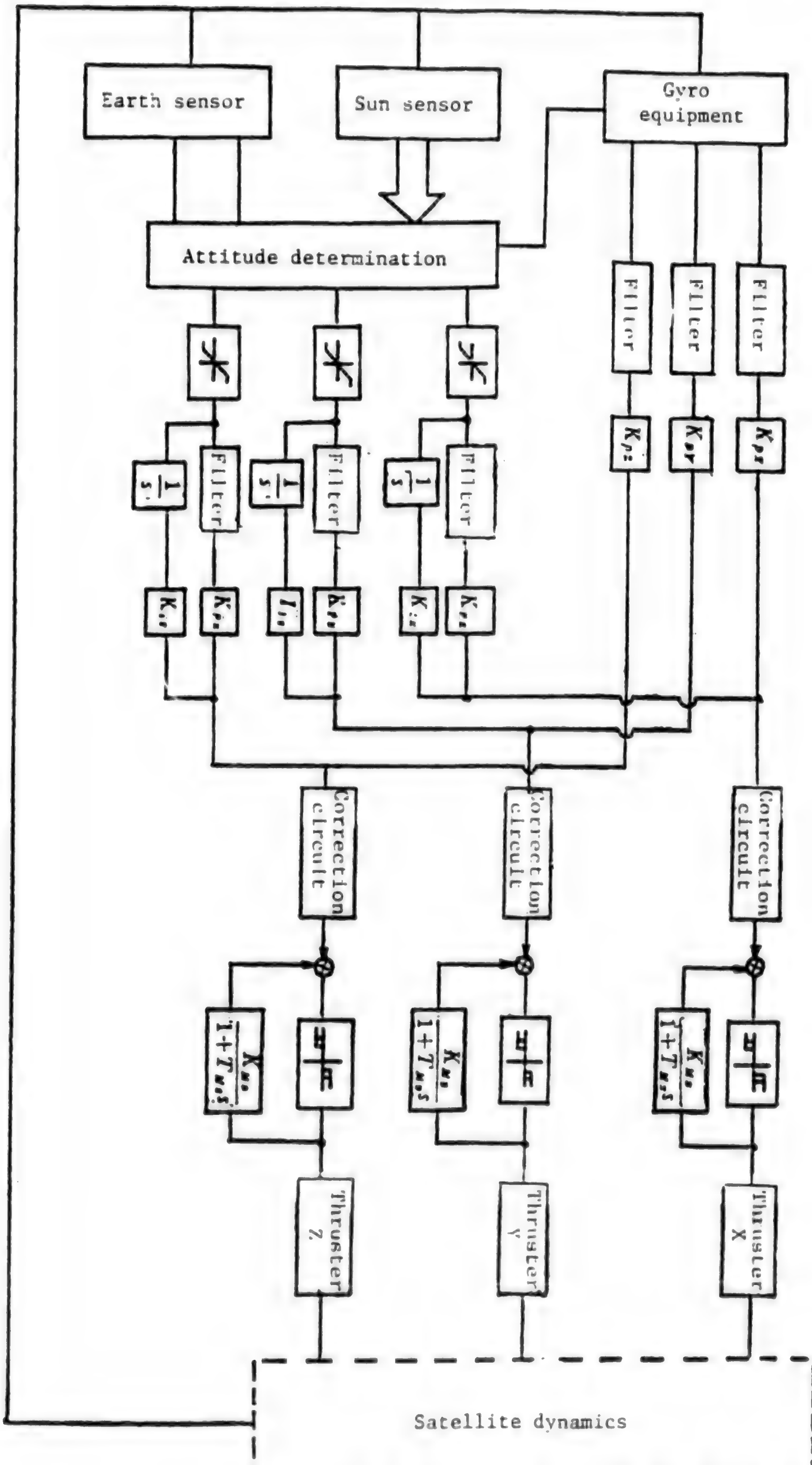

Figure 6. Stability Circuit for Apogee Orbit Change and Station Keeping

Thermal Control Technology for Communications Satellites

91FE0134F Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 45-51

[Article by Guo Jiurong [6665 0046 6954] of the Beijing Institute of Spacecraft Systems Engineering; MS received 5 August 89]

[Excerpts]

Abstract

This article briefly describes the current status and near-term prospects of thermal-control technology for communications satellites. Specifically, several problems related to heat radiators and other thermal-control elements are discussed.

Over the past 20 years, a significant number of communications satellites have been placed in geosynchronous orbits at different locations above the equator. During this period, significant progress has also been made in thermal-control technology to accommodate the design of both spin-stabilized and three-axis-stabilized geosynchronous satellites. But in recent years engineers are facing new challenges in thermal-control technology because of the many new developments in communications satellites.[1,2] [passage omitted]

II. Thermal-Control Techniques

The commonly used thermal-control techniques on communications satellites include: 1) thermal-control coating of secondary surface reflectors; 2) multi-layer insulation material; 3) heat pipes; and 4) electric heaters.

1. Thermal-Control Coating

The temperature of a satellite depends to a large extent on the solar absorptivity (α_s) of the satellite surface and the infrared emissivity (ε_H). Therefore, applying the proper thermal coating to the surface is of critical importance.

It is generally agreed that silver-coated quartz-glass secondary surface reflector (OSR) [optical solar reflector] is an ideal coating material for the radiators of long-service-life communications satellites. The unique feature of this coating is that it can dissipate the waste heat of the satellite very effectively because of its low absorptivity and high emissivity and its relatively stable material properties. However, the gradual degradation of OSR during on-orbit operation (i.e., gradual increase of absorptivity) will cause the temperature of the satellite to rise; this presents a difficult problem for the thermal designer. [passage omitted]

In this country, heat pipe has been successfully used on many spin-stabilized communications satellites. Its performance over the past 5 years has been stable and satisfactory. It should be emphasized that the position of the heat pipe on a spin-stabilized satellite must be carefully selected and its alignment be tightly controlled. [passage omitted]

4. Electric Heater

Almost without exception, domestic and foreign communications satellites all use electric heaters as an important means of thermal control.

There are two types of electric heaters: one is the polyimide-F46 thin-film electric heating plate (or belt), which is widely used for controlling the temperature of general onboard instruments and equipment; the other is the armoured high-temperature electric heating filament which can be wound around the attitude motor and other high-temperature units. [passage omitted]

III. Selecting the Location of the Radiator

[Passage omitted] When the thermal-control design of China's communications satellites was being finalized in the mid-seventies, it was decided to abandon the popular design where a solar screen was used as the main heat dissipation surface; instead, a special belt radiator was installed around the cylindrical section for heat dissipation.[4] The advantage of this design is that except for the shadow region, the belt is always illuminated by the sun and does not suffer blockage effects from other components. Consequently, the temperature remains relatively constant, and the temperature control of the on-board instruments and equipment can be easily achieved. Also, heat insulation materials are added to the solar screen to minimize the effect of surface temperature on the interior of the satellite. [passage omitted]

References

1. Peter C. Wise, "Spacecraft Thermal Control Technology: Design Challenges Into the 1990's," IAF-85-373, 1985.

2. Mitsunobu Watanabe, et al., "Thermal Design Concept for Large-Capacity Communications Satellites," IAF-85-374, 1985.

3. M. Kitada, et al., "Thermal Design and Test of the ETS-V," AIAA 86-1341, 1986.

4. Guo Jiurong, "Investigation of Several Problems in the Thermal Design of Spin-Stabilized Geostationary Satellites," CHINESE SPACE SCIENCE AND TECHNOLOGY, Vol 9, No 2, pp 58-64, 1989.

5. Helmut Kreeb and Walter Schwarzott, "The Thermal Control System of the German Direct Transmitting Communications Satellite TV-SAT," AIAA 80-0503, 1980.

6. Douglas R. Chalmers, et al., "Advanced Communications Satellite Thermal Design Using Variable East/West Radiators," AIAA 86-0065, 1986.

Microwave Transponders With Single Frequency Conversion

91FE0134G Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 52-59, 27

[Article by Chen Daoming [7115 6670 2494] of the Chinese Academy of Space Technology and Cui Junye [1508 7486 2814] of the Xian Institute of Space Radio Technology; MS received 29 July 89]

[Excerpts]

Abstract

This article describes the design, the technical requirements and test results of microwave transponders with single frequency conversion; these transponders are used on Chinese domestic communications and broadcasting satellites. The major components of the transponder are also briefly described.

I. Introduction

[Passage omitted] In April 1984, China successfully launched its first experimental communications satellite; the payload of this satellite consisted of a global-coverage antenna and two superheterodyne IF-amplification-type transponders. In 1986, an operational broadcasting and communications satellite was launched; its payload consisted of an antenna which covered the Chinese territory and two superheterodyne IF-amplification transponders. In March and December of 1988, two operational broadcasting and communications satellites, the Dongfang Hong-2A [DFH-2A] No. 1 and No. 2, were successfully launched; their payload consisted of a domestic-coverage antenna and four newly developed microwave transponders with single frequency conversion.

II. Microwave Transponders With Single Frequency Conversion

With the exception of a few special-purpose satellites and military satellites, most commercial communications satellites use microwave transponders with single frequency conversion. This type of transponder is a simple and reliable wide-band system which can easily accommodate an increased number of channels and expansion in communications capacity. This new transponder design was implemented and became operational on the two domestic broadcasting and communications satellites, the DFH-2A No. 1 and No. 2, within a relatively short time.

1. Transponder Design for the DFH-2A No. 1 and No. 2 Satellites

A block diagram of the transponder design is shown in Figure 1. Its main features are as follows:

(1) The conversion of the uplink and downlink frequencies is accomplished by a single down-converter; the entire transponder is a microwave system with single frequency conversion.

(2) Its design has a 4:3 channel redundancy; i.e., it provides four channels in order to ensure that at least three channels remain operational.

(3) The microwave receiver design has a 2:1 redundancy with a switch control. There are no other redundant components.

(4) In the transmitter section, two of the channels use TWTA's (traveling-wave-tube amplifiers) whereas the other two channels use SSPA's (solid-state power amplifiers).

(5) The communications and TT&C channels share the same TWTA. Prior to final orbit injection, the TWTA is used as power amplifier for the TT&C channel; after the satellite is on station, the TWTA is used as a power amplifier for the communications channel. The TWTA operation is controlled by a switch. Once the satellite is on station, the TT&C channel uses a low-power SSPA, and transmits telemetry signals via a directional antenna. This shared TWTA design eliminates the need for a medium-power amplifier for TT&C, and avoids interference between communications and TT&C channels due to sharing of the same power amplifier.

2. Specifications and Typical Test Results of the Transponder

Table 1 presents the design specifications and typical test data of the transponder. It can be seen that all test results meet or exceed design requirements. Typical test curves are presented in Figure 2-Figure 4.

Table 1. Specifications and Test Results of the Transponder

Parameter	Specification	Test result
Total number of satellite channels	4	
Number of channels simultaneously in operation	3	4
Frequency range (GHz)		
Uplink	6.05-6.425	Meets specification
Downlink	3.825-4.2	Meets specification
Frequency resolution	$+/-6 \times 10^{-6}$	2.96×10^{-6}
Channel usable bandwidth (MHz)	36	>36

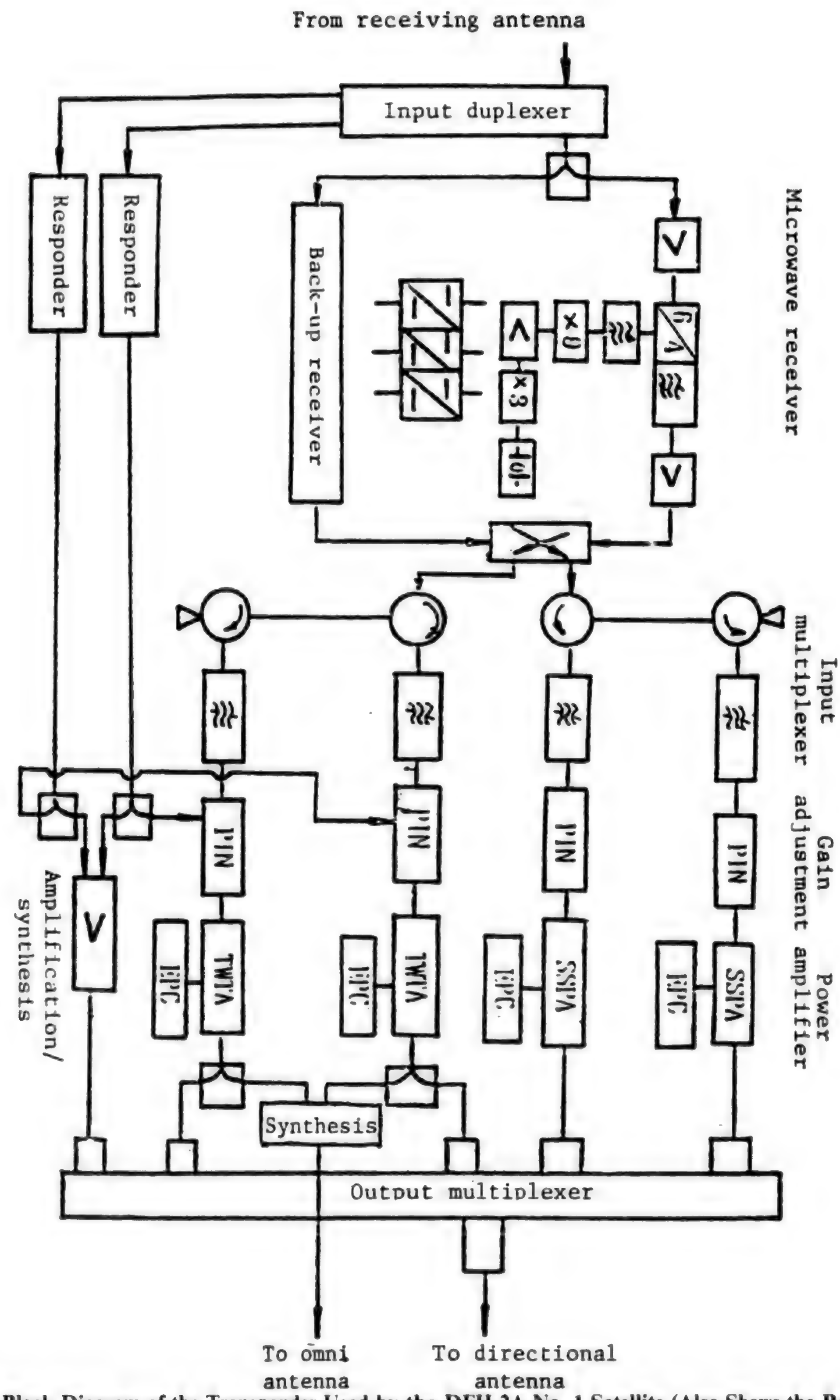

Figure 1. Block Diagram of the Transponder Used by the DFH-2A No. 1 Satellite (Also Shows the Relationship with the TT&C Channel)

Inter-modulation products between in-band local-oscillator harmonics and the carrier (dBc)	≤-50	-58
Noise figure (dB)	≤7.0	4.55
Transponder saturated output power (W)	10	10.5
Gain adjustment range (dB)	6	15
Saturated input flux density (dBW/m^2)	-84	-85
Saturation within 70 percent of bandwidth, gain slope (dB/MHz)	≤0.1	≤0.1(100percentbandwidth)
Gain variation within the usable bandwidth (dB_{pp})		
BO_i = 0 dB	≤1.0	0.5
BO_i = -6 dB	≤1.2	0.6
Third-order inter-modulation C/IM_3 (dB)		
BO_i = 0 dB	≥10	10.4
BO_i = -6 dB	≥16	17.7
Amplitude modulation/phase modulation (AM/PM) conversion coefficient (°/dB)	≤8	4.4
Group-delay variation within the usable bandwidth (ns)		15.6

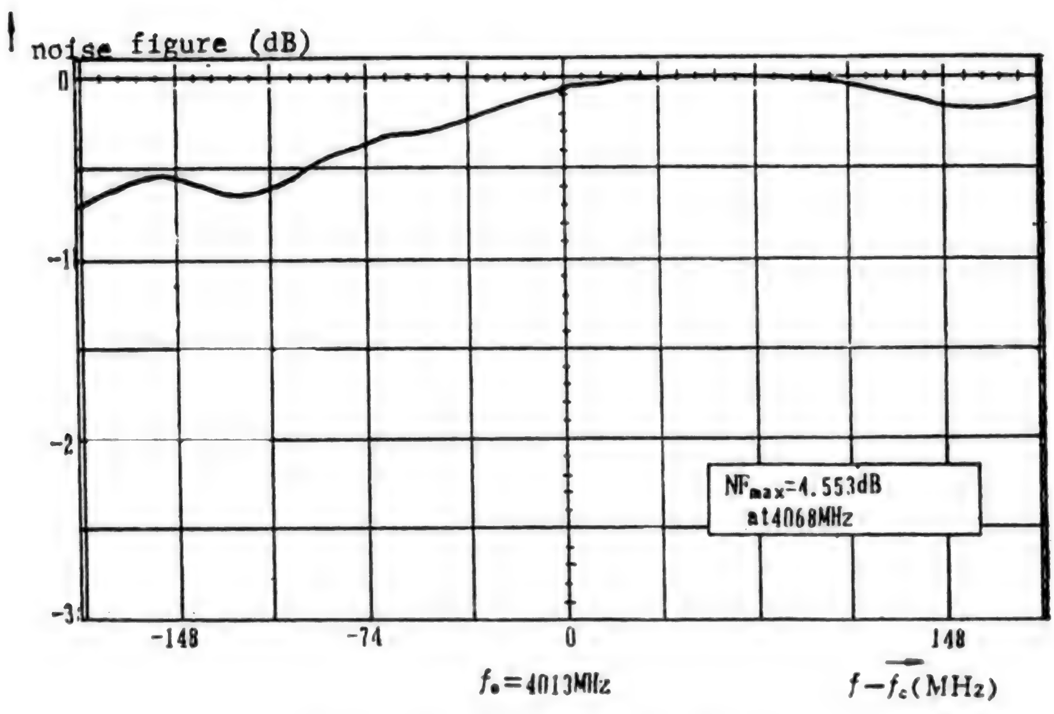

Figure 2. Transponder System Noise Figure

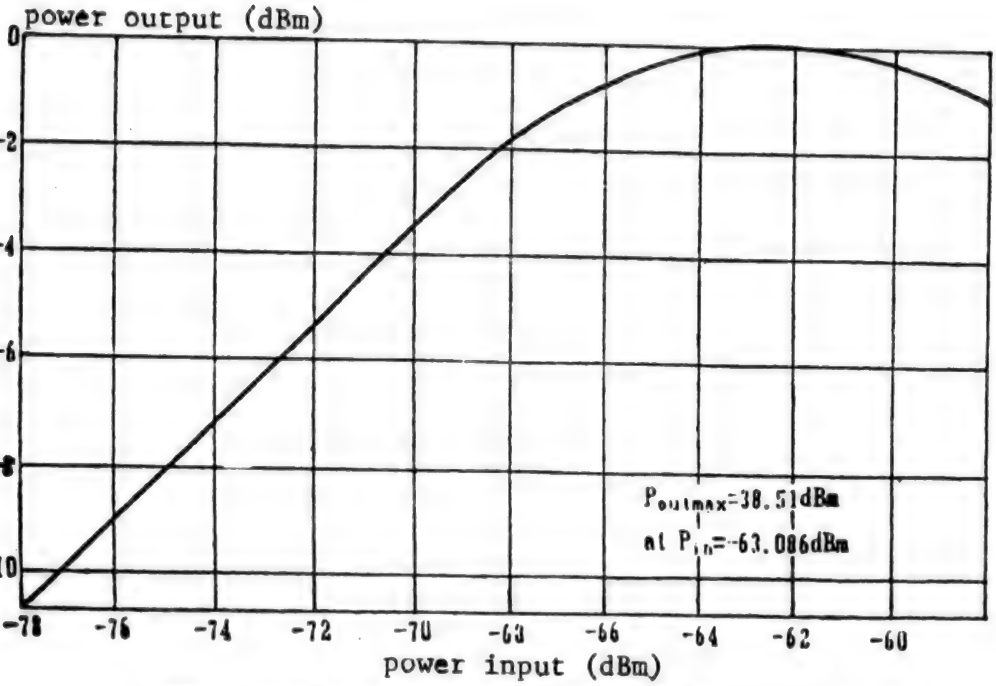

Figure 3. Typical Input-Output Characteristics of the Transponder

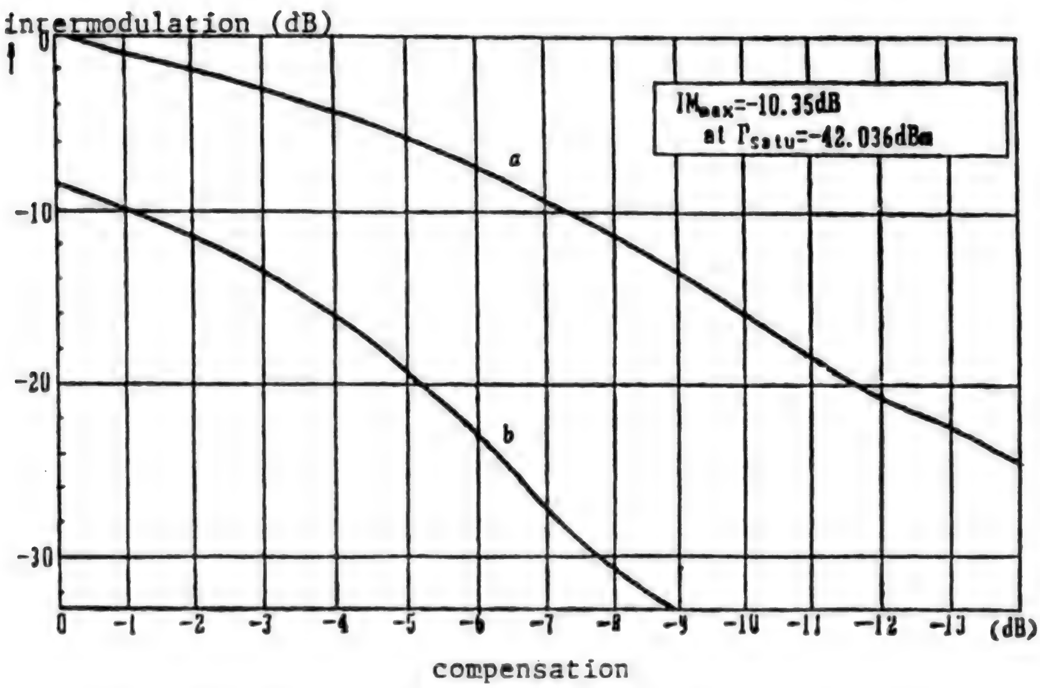

Figure 4. Typical Inter-Modulation Characteristics of the Transponder. a. IM 3; b. IM 5

3. On-Orbit Test Results

Table 2 presents the main results of the on-orbit test, which is a test of the complete payload system. The results of Table 2 and the curves shown in Figure 5 and Figure 6 indicate that the transponder's performance has met or exceeded design specifications.

Table 2. On-Orbit Test Results of the DFH-2A No. 2 Satellite

Parameter	Test result	Note
Effective isotropic radiated power $EIRP_s$ (dBW)	37.7,36.9,35.2,35.3	Beam center
Quality factor G/T_s (dB/K)	-1.96,-2.09,-2.53,-3.42	Beam center
Input saturated flux density W_s (dBW/m^2)	-81.9,-82.0,-84.2,-85.0	Beam center
Frequency resolution	5.8×10^{-6}	
Gain adjustment range (dB)	15.35,14.35,14.05,15.5	
Third-order intermodulation C/IM_3 (dB)		
$BO_i = 0$ dB	11.1,11.1,11.6,10.3	
$BO_i = -6$ dB	17.2,17.0,19.4,19.0	
AM/PM conversion coefficient K_p (°/dB)	1.33,1.87,3.98,3.79	Earth station D = 11 m
Carrier-to-noise ratio C/T_s (dBW/K)	-129.3,-129.9,-131.9,-131.6	Beam center
Gain variation (dB_{pp})		
$BO_i = 0$ dB	1.0,0.96,0.72,0.9	
$BO_i = -6$ dB	1.2,1.04,1.28,1.6	

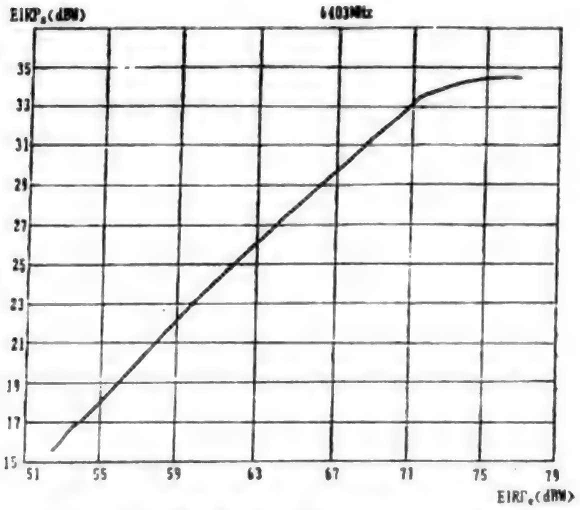

Figure 5. Input-Output Characteristics of the Transponder (On-Orbit Test)

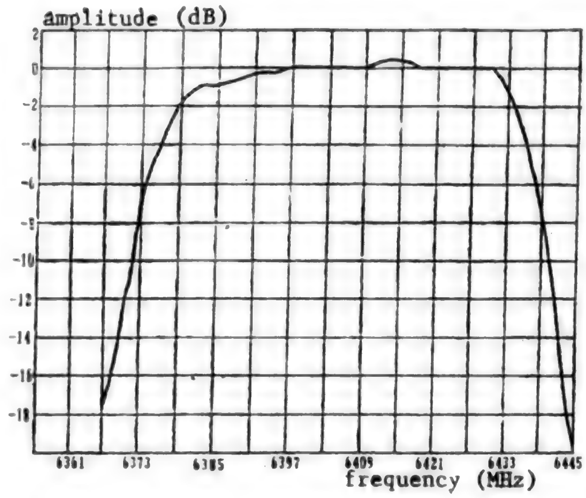

Figure 6. Amplitude-Frequency Characteristics of the Transponder (On-Orbit Test)

4. Discussion of Certain Design Issues

In order to meet the required specifications, the following issues should be given serious consideration in the system design.

(1) For a wideband system with single frequency conversion, the stability problem is of great importance. In particular, the radiation leakage from the transmitter and the radiated power through the antenna into the receiving unit may cause unstable oscillation due to system feedback.

(2) Another important issue is the electromagnetic compatibility between the C-band transponders and the TT&C equipment which also uses C-band.

(3) The system noise figure is primarily determined by the performance of the low-noise amplifier of the receiver and the input cable loss.

(4) For fixed saturated output power and fixed antenna gain, the feed cable loss should be minimized to enhance EIRP.

(5) The frequency stability requirement can be met by using a simple crystal-controlled oscillator, but the margin is very small.

(6) The compatibility between C-band satellite channels for both domestic and foreign use is taken into consideration when assigning frequency bands for the four transponder channels. Also, the four frequency bands are

shifted by an appropriate amount to meet isolation requirements between channels.

(7) The channel divider (input multiplexer) uses a linear phase filter and has a bandwidth which is slightly wider than the usable bandwidth in order to achieve a balance between time delay and amplitude within the usable bandwidth.

(8) A relatively wide gain-control range is used to accommodate various gain adjustments for different satellite missions.

(9) Sufficient isolation should be provided between all the links leading to the directional antenna and the omni antenna (e.g., isolation of the switch connected to the TWTA) so that interference between the directional and omni antennas is kept to a minimum. As an example, in order to keep the fluctuations of the omni-antenna pattern caused by interference to less than +/-0.5 dB, the isolation should be higher than 55 dB.

III. Description of the Major Components

In this section, the major components of the DFH-2A No. 1 and No. 2 satellites and their performance are briefly described.

1. Microwave Receiver

This is one of the key components of the microwave transponder with single frequency conversion. The conversion of the uplink and downlink frequencies is accomplished inside the receiver. It is a single-frequency-conversion receiver which uses an LNFETA (low-noise field-effect-transistor amplifier) as its low-noise unit and FETA (field-effect-transistor amplifier) as its amplification unit. This type of receiver was first used abroad on communications satellites in the 1980's. In this country, this is the first time that this receiver has been developed and used on satellite transponders.

The receiver consists of three sections: the microwave channel, the local oscillator (LO) and the power supply. The microwave channel contains the LNFETA, the Schottky-barrier-diode frequency-mixer, the FETA (i.e., the high-gain post-amplifier), the band-pass and band-rejection filters, and the PIN-diode temperature compensator. The variable-frequency LO consists of the crystal-controlled oscillator, the frequency multiplier, the power amplifier, the step-[recovery]-diode frequency multiplier, and three types of filters. The receiver power supply is a d.c. transform circuit with combined switch-voltage stabilization and series-voltage stabilization; it provides effective protection for the FET.

Table 3 presents typical performance data of the receiver, and Figure 7 shows the typical curves of gain characteristics.

Table 3. Typical Performance Data of the Receiver

Frequency range (GHz)	
Input	6.0-6.425
Output	3.775-4.2
Local oscillator (LO) frequency (GHz)	2.225
Frequency resolution	2.96×10^{-6}
Monthly frequency stability	1×10^{-6}
Long-term frequency stability	1×10^{-5}
Noise figure (dB)	≤3.4
Gain (dB)	68
Gain variation within the frequency range (dB_{pp})	1.0
Gain slope (dB/MHz)	≤0.01
Compression-point output power with 1 dB gain (dBm)	≥20
Intermodulation products between the carrier and the LO harmonics within the frequency range (at -68 dBm input) (dBc)	-58
Input/output standing-wave ratio (SWR)	1.25/1.25
Second-harmonic output of the LO frequency (dBm)	-37.4
Power consumption (W)	3.5
Weight (kg)	3.0

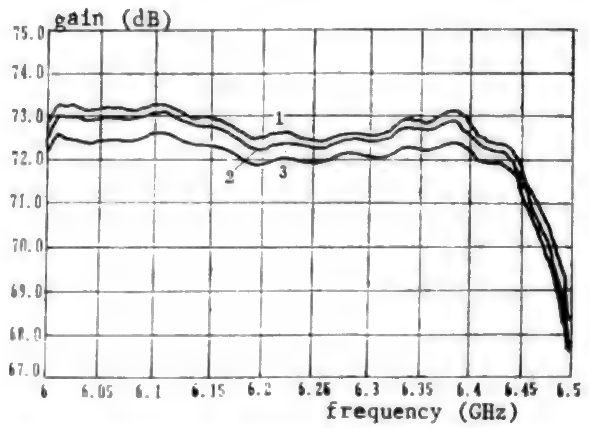

Figure 7. Typical Gain Characteristics of Microwave Receiver; Signal power: 1, -66 dBm; 2, -60 dBm; 3, -54 dBm

2. Input and Output Multiplexers

The multiplexers are developed based on the dual-mode elliptic-function band-pass filter. The input multiplexer is composed of four band-pass filters, ferrite circulators and isolators; it divides the downlink frequency band into four precisely defined channels. The output multiplexer is a five-channel synthesizer (including the downlink telemetry channel), which consists of a band-pass filter, a waveguide manifold and a low-pass filter. Figure 8 and Figure 9 show typical performance curves of the two multiplexers.

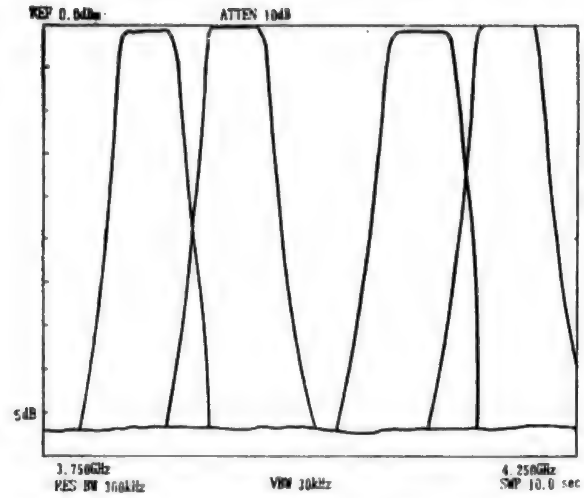

Figure 8. Inter-Channel Isolation Characteristics of the Input Multiplexer

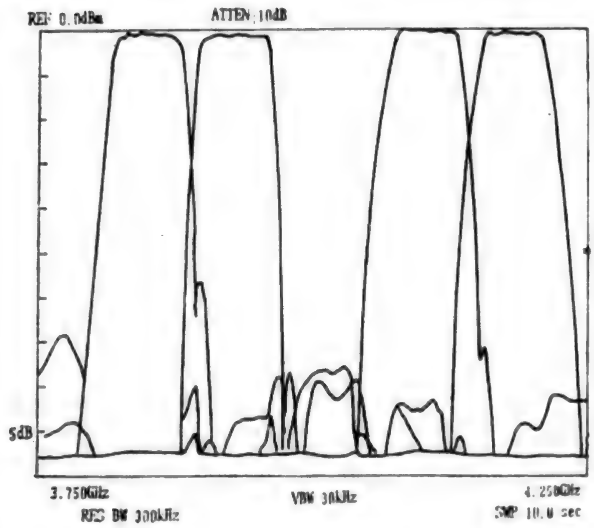

Figure 9. Inter-Channel Isolation Characteristics of the Output Multiplexer

The input and output multiplexers are critical components of the microwave transponder. In general, to expand the capacity of the transponder or to increase the number of transponders only requires redesign of these multiplexers.

3. TWTA and SSPA

The TWTA consists of the traveling-wave tube and the power supply; its typical performance characteristics are presented in Table 4.

Table 4. Typical Performance of TWTA

Frequency range (GHz)	4.0-4.2
Saturated output power (W)	10.5
Gain (dB)	
Saturated	60.7
Small-signal	63.7
Gain slope (dB/MHz)	≤0.02
Gain variation within the frequency range (dB_{pp})	
Saturated	0.22
Small-signal	0.57
Third-order intermodulation product C/IM_3 (dB)	
BO_i = 0 dB	10.63
BO_i = -6 dB	17.18
AM/PM conversion coefficient (°/dB)	4.2

The power supply of the traveling-wave tube requires five voltage levels; the highest anode voltage is approximately 2100 V. The power to the TWT is provided by the primary power source of the satellite; specifically, a switched-voltage-stabilizing transformer is used to supply different levels of output voltage to the TWT. The design of the TWTA is a technically challenging task because the unit must begin operation prior to launch, and it must operate under different pressure conditions ranging from atmospheric pressure to vacuum, without producing a corona.

The SSPA is made of microwave FET's. It contains a three-stage small-signal amplification segment and a three-stage power amplification segment. The final-stage amplification consists of four power FET's whose in-phase excited post-amplified outputs are synthesized to produce a 10-Watt power output. The SSPA also contains a PIN-diode temperature compensator and a dedicated amplifier power supply. The key technical performance data of the SSPA are presented in Table 5.

Table 5. Performance Data of the SSPA

Frequency range (GHz)	3.7-4.2
Rated input power (dBm)	-18
Maximum input power (24h) (dBm)	-5
Maximum output power (dBm)	40 (10 W)
Maximum input SWR	<1.3
Rated output SWR	<1.2
Noise figure (dB)	<10
Single-carrier gain (dB)	
At saturation	≥56
At 1-Watt output power	≥61
Gain variation in any 40-MHz band (dB_{pp})	
At saturation	<0.2
At 1-Watt output power	<0.4

Table 5. Performance Data of the SSPA (Continued)

Frequency range (GHz)	3.7-4.2
Gain slope (dB/MHz)	
At saturation	<0.01
At 1-Watt output power	<0.02
Gain stability (dB_{pp})	
Large-signal	0.5
Small-signal	0.8
Third-order intermodulation product C/IM_3 (dB)	16
Rated d.c. power consumption (V)	28-43 (44 W)

The power amplifier is a critical component of the transmitting section of the transponder; in general, a redundant unit is provided in the satellite transponder system to improve system reliability.

IV. Concluding Remarks

The performance of the microwave transponder with single frequency conversion has met or exceeded design specifications. The successful development and implementation of China's first microwave transponder has laid a solid technical foundation for the future development of high-capacity, multi-channel transponders operating in the same frequency band and with the same type of system.

The DFH-2A No. 1 satellite is China's first operational communications satellite; the DFH-2A No. 2 is a backup satellite. Both satellites have become operational to provide television services at the central and local levels, educational television services, and military and commercial communications and broadcasting services. However, with the ever-growing satellite communications industry, China is currently planning the development of a high-capacity communications satellite [DFH-3] to meet the increasing demand.

In closing, the author wishes to express his thanks to the 30 assistant engineers, engineers and senior engineers who participated in the development of the microwave transponder with single frequency conversion. Thanks are also due to senior engineers Wu Xuda, Xiong Hongfu, and He Xianze for providing the test curves and performance data of the multiplexer and the TWTA.

References

1. G. Maral, M. Bousquet, "Satellite Communications Systems."

2. Chen Daoming, Cui Junye, "The Chinese Communications Satellite Transponders," ECSC-I, Symposium 1989.11 [see JPRS-CST-90-003-L, 1 Jun 90, pp 62-79].

3. Chen Daoming, "China's Broadcasting and Communications Satellites," DIANXIN KUAIBAO [TELECOMMUNICATIONS INFORMATION], No 5, May 89 [see JPRS-CST-89-019, 25 Sep 89, pp 33-45].

Electrical Design of Antenna Subsystem of High-Capacity C-Band Satellite

91FE0134H Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 1, Feb 90 pp 60-66, 35

[Article by Guo Wenjia [6753 2429 0857] of the Xian Institute of Space Radio Technology; MS received 12 October 89]

[Excerpts]

Abstract

This article discusses the design of the antenna subsystem for C-band high-capacity communications satellites. Specifically, based on the system requirements and design boundary conditions, a method of designing the antenna beam contour for satellite operation at two different orbital positions is described. The solutions to a number of design problems, particularly the problem of the beam-forming network, are presented. Finally, the optimal design of the antenna subsystem at the second orbital position and the predicted performance of the second satellite are also presented.

I. Boundary Conditions for the Design of Antenna Subsystem for C-Band Communications Satellites

1. Basic Design Requirements

To satisfy China's growing needs for communications and television broadcasts, a decision based on China's current technical capabilities was made to develop a C-band high-capacity communications satellite. The basic requirement of the satellite is to design a payload with 24 transponders capable of simultaneous operation; the coverage requirements are as follows: EIRP $\geq$ 38 dBW for television rebroadcast, so that the large number of TVRO [TV receive-only] stations with small-aperture antennas (less than 3 m) can receive and re-transmit TV signals; EIRP $\geq$ 35 dBW for communication channels, so that ground stations with 6-m-aperture antennas can receive and transmit communications signals.

2. Candidate Designs

A comparison has been made between several feasible designs which satisfy the basic requirements of Section 1, and a set of design rules which are based on the results of compromise and optimization among many factors have been established.

(1) Based on the coverage requirement of the service area and the capability of the launch vehicle, a 2-m-aperture offset paraboloid reflector antenna is chosen.

(2) In order to satisfy the requirement of EIRP coverage over the service area, it is necessary to use a shaped-beam antenna so that as much energy as possible would be focused on the service area.

(3) In order to meet the requirement of concurrent operation of 24 transponders and the isolation requirement of cross-polarized voltages, it is necessary to use polarization diversity and frequency reuse (FDM) technology, which involves the design of a polarization-sensitive, double-screen paraboloid reflector.

(4) In order to satisfy the requirement of simultaneous operation of 12 transponders within a 500 MHz band for each polarization, and in view of the fact that the microwave output multiplexer cannot operate continuously in a multiplexed mode, it is necessary to use an odd-even synthesizer design for the beam-forming network so that the odd-channel signals and the even-channel signals can be fed simultaneously to the antenna beam-forming network. Furthermore, the entire beam-forming network must meet the following requirements: large bandwidth, low power consumption and compact size.

The above description shows that this C-band high-capacity communications satellite imposes very stringent requirements on the payload design; the level of design difficulty exceeds that of other communications satellites previously developed in this country.

II. Electrical Design of Communications Antenna

1. Shaped-Beam Design Using a Multiple-Feed Offset Paraboloid Surface

The offset paraboloid antenna has some desirable features such as no aperture blockage, structural simplicity and complete foldability; since 1980 it has been widely used in multiple-feed, shaped-beam antenna systems for satellite applications.[1]

The so-called multiple-feed shaped beam is formed by using a number of feed sources to illuminate the paraboloid reflector to produce an array of beamlets in the service area;

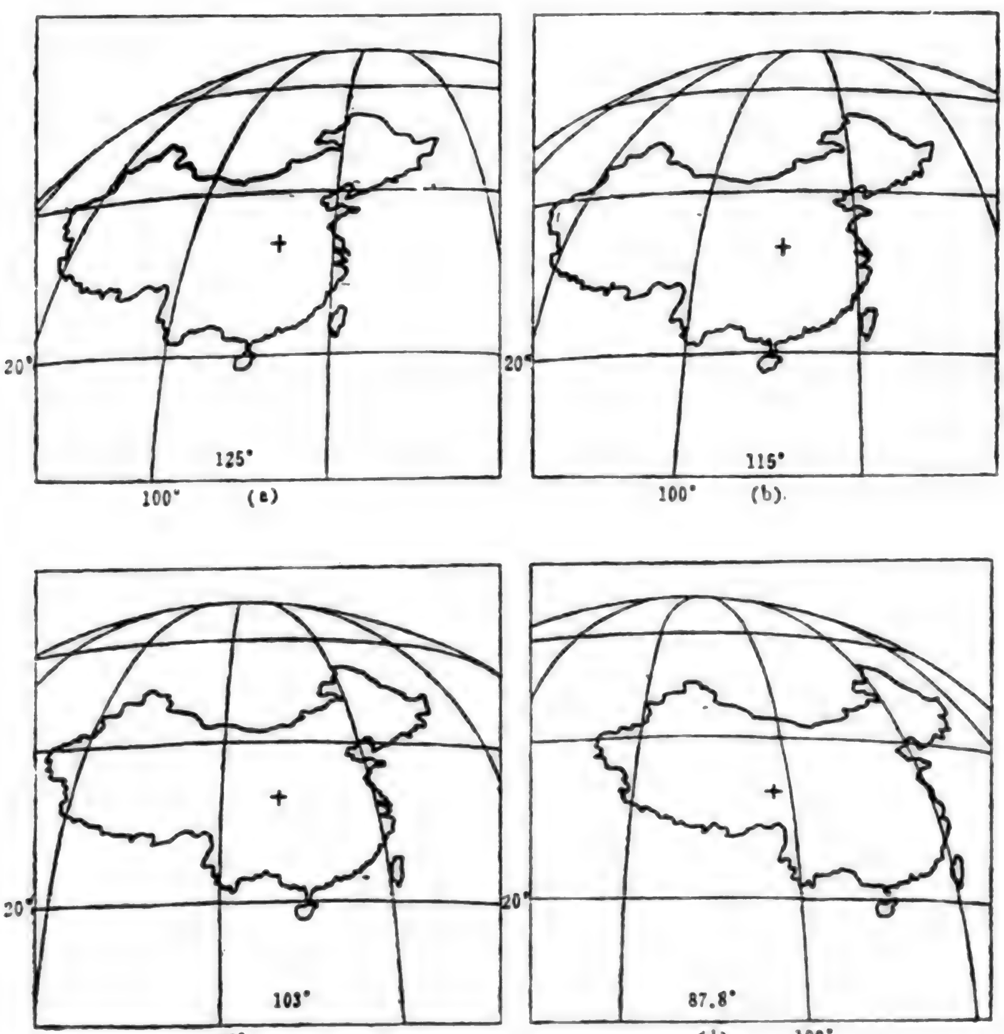

Figure 1. Perspective Views of the Service Area at Four Different Orbital Positions: 125°, 115°, 103°, 87.5°

these beamlets are excited by a selected set of amplitude and phase coefficients to obtain a beam shape which matches the shape of the service area. In principle, the narrower the beamlets, the better the shaped beam can match the shape of the service area; however, in practice not all beamlets can be made very narrow due to the constraints of the operating frequency and the allowable size and weight of the antenna. For example, the beamlets produced by a 2-m-aperture C-band antenna have a 3-dB beamwidth of approximately 2.6 degrees.

Figure 1 shows different perspective views of the service area from four satellite orbit positions: 125°, 115°, 103° and 87.5°. These four pictures show that the Chinese territory spans 7° in the east-west direction and 4° in the north-south direction. This corresponds to four beamlets in the east-west direction and two or three beamlets in the north-south direction produced by a 2-m-aperture antenna at C-band; the total number is approximately seven or eight beamlets.

On the basis of optimal design requirements, the aperture (or spacing) of each feed should be 1.1-1.5 wavelengths; a smaller aperture size (or spacing) will cause serious coupling effects whereas a larger spacing will create grating lobes and result in energy loss which will appear as depressions in the synthesized beam. The C-band antenna for the current design must cover 4/6 GHz and must first meet the downlink coverage requirement. For this reason, the aperture size is chosen to be 1.1 wavelengths based on the lowest downlink frequency; this corresponds to an aperture-to-wavelength ratio of 1.9 based on the highest uplink frequency.

2. Feasibility of Satellite Operation at Two Different Orbital Positions

It can be seen from Figure 1 that the shape of the service area changes considerably with different orbital positions; generally, each service-area shape can be enclosed in a 4° x 7° ellipse. But, if the shaped beam is matched to the service

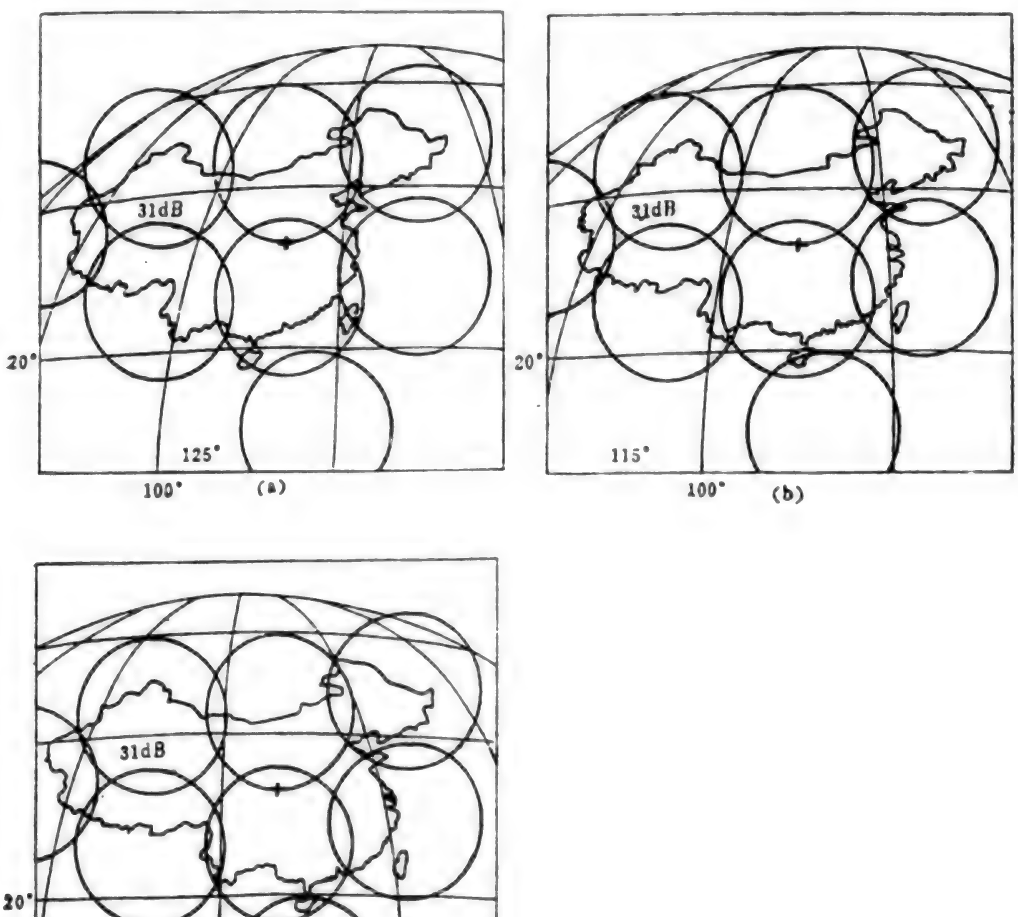

Figure 2. Beamlet Array Diagrams at Three Orbital Positions: 125°, 115°, 103°

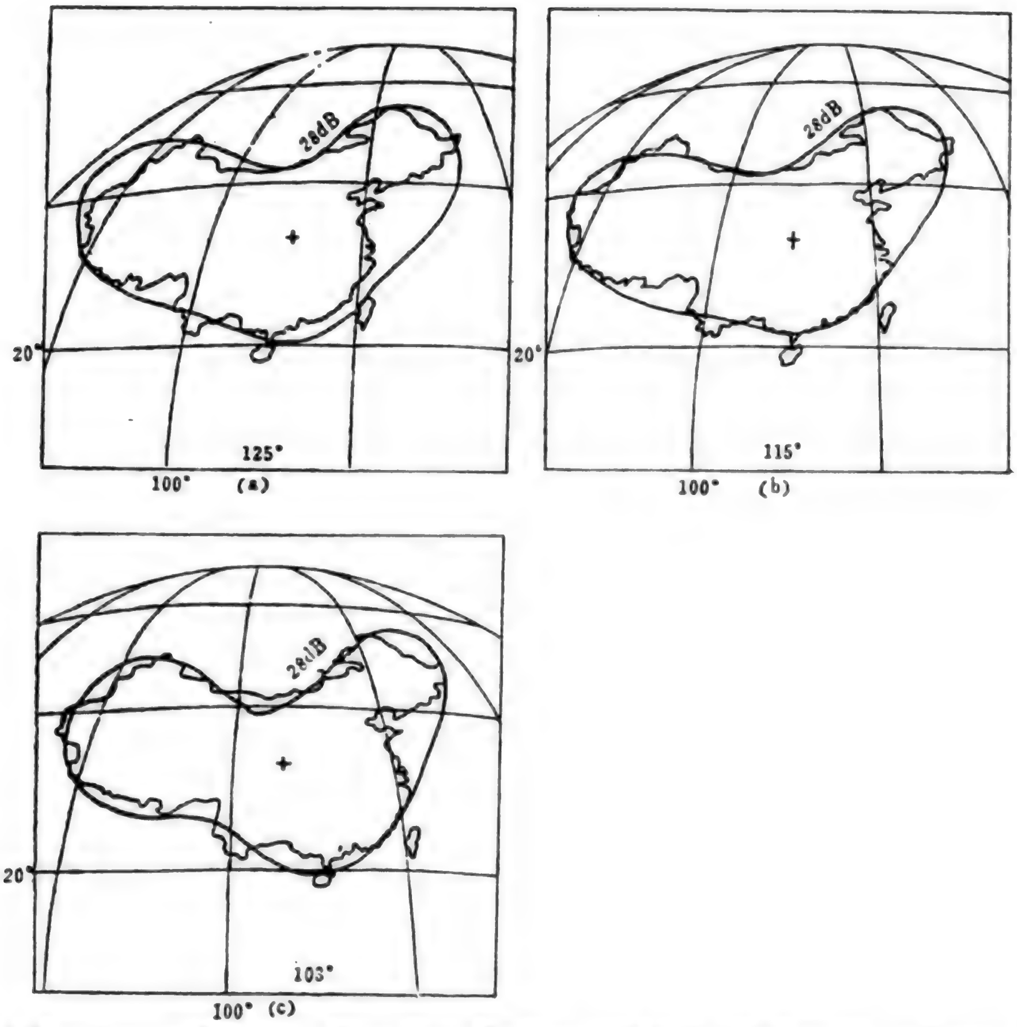

Figure 3. Beam Coverage Diagrams at Three Orbital Positions: 125°, 115°, 103° (directivity coefficient = 28 dB)

area at one particular orbital position, the EIRP optimized for that position may be significantly degraded when the beam is moved to a different position. The wider the separation between the two orbital positions, the larger the degradation. The optimal coverage of the service area depends on two factors: the first is optimization of the beamlet array in the service area; the second is optimization of the amplitude and phase excitation of the beamlets. Therefore, the first step in designing the antenna subsystem is to find an array of beamlets such that the satellite can operate at different orbital positions by simply changing the amplitude and phase excitation of the beamlets. This technique is called the beam re-forming technique, which allows the satellite to operate in a range +/-12° from its optimal orbital position without adding other beamlets. Figure 2 shows an example of a beamlet array which is centered at 115°, but can operate at 125° to the east and 103° to the west. Coverage of the service area at different orbital positions in this range can be achieved by properly changing the amplitude and phase. Figure 3 shows the coverage diagram for these three orbital positions under dual-mode operation.

In order to reduce the development cost of the onboard antenna and to facilitate changing the amplitude and phase excitation of the beamlets, two 3-dB bridge circuits with adjustable phase shifters are used to implement changes of the power distribution ratio. To operate the satellite at two different orbital positions, it is only necessary to adjust the phase shifters in the beam-forming network to obtain a set of new excitation coefficients. If the satellite is equipped with onboard electrical shifters, then the beam shape can be changed by remote control of the phase from the ground. The disadvantage of this technique is that many 3-dB bridge circuits must be used in the beam-forming network, which makes the network more complicated and increases power consumption. But, by using microwave passive-element integrated-circuit (IC) technology, this type of network is realizable from the engineering point of view. Another design issue of the antenna subsystem is that it must take into consideration such factors as temperature control and thermal deformation, because the antenna will encounter a wide range of temperatures as the satellite moves to different orbital positions.

3. IC Technology for Passive Elements in the Beam-Forming Network

The beam-forming network is a key element of the multiple-feed shaped-beam antenna. With increasing demand on the performance of shaped-beam antennas, a larger number of beamlets is required. [passage omitted] In the mid-1980's, beam-forming networks using IC technology first appeared; a typical example was the beam-forming network of the INTELSAT-V antenna, which used planar medium-support, air-belt type ICs. [passage omitted] Since that time, planar IC technology using square coaxial cable for C-band application has been developed. Computer-aided design techniques and computer-controlled processing techniques are used to fabricate the complicated ICs. The C-band high-capacity communications satellite which is currently under development in this country also uses this advanced technology to reduce the size and weight of the antenna subsystem.

In order to satisfy the requirement of simultaneous operation of 12 transponders for each polarization and to overcome the difficulty of maintaining continuous multiplexer output, an odd-even channel synthesizer is added to the beam-fc ming network. The synthesizer has two input terminals; one terminal is connected to the output multiplexer of the odd channel transponder and the other terminal is connected to the even channel. The number of output terminals may be 2, 3 or 4; however, in order to ensure that the odd and even channels produce consistent beam shapes and to ensure sufficient isolation between the two channels, the odd-even synthesizer must satisfy the following conditions:[2]:

$$\langle T^{o} \bullet T^{e} \rangle = 0 \qquad (1)$$

$$T^{o} = (T^{e})^{*} \angle \phi \qquad (2)$$

where T^0 denotes the transmission coefficients of the output terminals T^0_1, T^0_2 ... T^0_N for an odd-channel input; T^e denotes the transmission coefficients of the output terminals T^e_1, T^e_2 ... T^e_N for an even-channel input.

The first equation indicates that the conjugate product of the odd-mode transmission coefficients and the even-mode transmission coefficients must be zero; the second equation indicates that the amplitudes of the corresponding transmission coefficients of the two modes are equal, and the phases of the two conjugates differ by a constant. The odd and even synthesized outputs which satisfy the above conditions are orthogonal, and the beam shapes produced by the two modes are in close approximation to one another.

The 2-3 odd-even synthesizer design is shown in Figure 4. By requiring a certain power ratio at the three output terminals, a corresponding set of phase distributions can be obtained. With input from the odd terminal, if terminal b is the zero-phase reference point, then terminal a leads terminal b in phase, and terminal c lags terminal b. With input from the even terminal, if terminal b is the zero-phase reference point, then terminal a lags terminal b in phase, and terminal c leads terminal b. Since there are three output terminals, it is necessary to divide the beamlets into three groups; in the grouping process, one must keep in mind that the group of beamlets which are fed by the zero-phase reference terminal should be located in the center of the beamlet array. The two groups of beamlets with positive and negative phases should be located on two sides of the center beamlets in order to avoid large phase differences between neighboring beamlets. Table 1 shows the phase distribution at the output terminals of the synthesizer under different amplitude distributions; the symbols φ_a, φ_b, φ_c denote the respective phases at the three output terminals a, b and c.

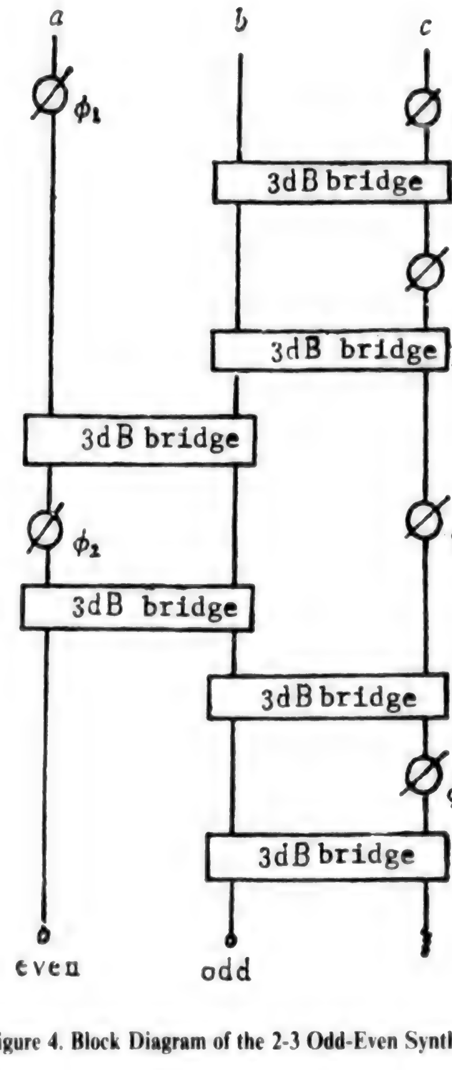

Figure 4. Block Diagram of the 2-3 Odd-Even Synthesizer

Table 1. Output Amplitude Ratio and Phase Distribution of the 2-3 Odd-Even Synthesizer

Amplitude ratio	1:1:1			1:0.9:0.8			1:0.9177:0.8885		
Odd mode	φ_a	φ_b	φ_c	φ_a	φ_b	φ_c	φ_a	φ_b	φ_c
	60°	0°	-60°	70.15°	0°	-46.82°	65.08°	0°	-52.24°
Even mode	-60°	0°	60°	-70.15°	0°	46.82°	-65.08°	0°	52.24°

With the odd-even synthesizer in the beam-forming network, the synthesized beam contour must be optimized with respect to both modes in order to obtain a set of optimal excitation coefficients under dual-mode operation. It should be pointed out that the coverage contour optimized for dual-mode operation is generally 0.5 dB lower than the coverage contour optimized for single-mode operation (all other conditions being equal).[3] The reason is quite clear: the use of an odd-even synthesizer introduces unwanted phase in the beam-forming network which varies with the operating mode; this imposes additional constraint conditions in the optimization of the feed excitation coefficients. If the design requirement calls for the beam coverage of certain channels to be better than other channels, then the optimization process can be carried out with respect to a single mode or a selected number of channels at the expense of other modes or other channels.

III. Design Results of the Beam Coverage of the Second Satellite

In engineering design, quite often the design of a first satellite is optimized with respect to one set of conditions without regard to the coverage of a second satellite which may be stationed at a different orbital position. In this case, the second satellite is often subject to many design constraints because it generally uses the hardware originally built for the first satellite. These constraints include the following (in addition to the problems described in Section 2):

—The feed array structure will be constrained by the array configuration and dimensions of the first satellite. This prevents complete optimization of the beamlet array.

—The choice of polarization must be consistent with that of the first satellite; this constraint is actually also reflected in the inability to choose another beamlet array.

—All geometric dimensions and weights must be consistent with those of the first satellite.

Under these conditions, the only parameters that can be adjusted are the feed excitation coefficients. Figure 5(a) shows the beamlet array diagram which has been optimized for the service area at the orbital position of 125° but moved to the position of 103°; clearly, the design is less than optimal. Figure 5(b) shows the coverage diagram after adjusting the excitation amplitude and phase under the same conditions. At 125°, the beamlet array can satisfy 90 percent of the specified service-area requirements; whereas at 103°, only 84 percent of the requirements can be met. This example clearly shows that if the design of a first satellite is optimized for one particular orbital position, then a second back-up satellite operating at a different orbital position is likely to suffer certain degradation.

Figure 5. Beamlet Array and Beam-Coverage Diagram of the Second Satellite at 103° (directivity coefficient = 28 dB)

IV. Conclusion

The above discussion shows that the technology used by the antenna subsystem of the C-band high-capacity communications satellite matches with the state-of-the-art technology used by foreign domestic communications satellites. But, because of a number of very challenging problems encountered in our design, considerable efforts had to be devoted by China's engineers to successfully develop an antenna subsystem. Also, the problems discussed in this article are only concerned with the electrical design; significant design efforts are also required in other areas such as measurement, structure, temperature control, etc., to ensure the overall success of the antenna design.

The data presented in this article are calculated using the "Computer-Aided-Design Software for Shaped-Beam Antennas."

The author wishes to express his thanks to Chen Ziyuan for proofreading the manuscript, and to the Dongfang Hong-3 [DFH-3] Communications Satellite Antenna Design Group for providing valuable data and other information.

References

1. R. Mittra, W. A. Imbriale, E. J. Maanders, "Satellite Communication Antenna Technology," North-Holland, 1983.

2. Howard. H. S. Luh [as published], "A Variable Power Dual Mode Network for Reconfigurable Shaped Beam Antenna," IEEE AP-32 (1984) p 1382.

3. Li Ronglong, Wu Ji, Yi Nianxue, Guo Wenjia and Shi Yixin, "Single and Dual Mode Optimization for Satellite Contoured Beam Antennas," Proceedings of Second International Symposium on Antennas and EM Theory, pp 267-270.

Control of Solid Apogee Motor During Orbit Transfer Maneuver

91FE0134I Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 2, Apr 90 pp 5-9

[Article by Zhang Yuntong [1728 0061 1749] of the Beijing Institute of Spacecraft Systems Engineering; MS received 13 July 89]

[Excerpts]

Abstract

This article presents a method for determining the optimum ignition time and optimum attitude of the apogee motor during the launch of a geostationary satellite.

I. Introduction

During the launch of a geostationary satellite, the onboard apogee motor provides the required delta velocity (ΔV) that changes the transfer orbit into a geostationary orbit. For a spin-stabilized satellite, the direction of the delta-V vector lies along the spin axis. To control the apogee motor to achieve the orbit change involves determining the ignition time and the direction of the spin axis (commonly referred to as the ignition attitude) based on the measured transfer orbit.

Different ignition times and ignition attitudes will produce different orbits after engine cut-off; therefore, it is necessary to choose the ignition time and ignition attitude such that the resulting orbit is an optimum orbit. In practice, the choice of these parameters is often subject to certain constraints; hence the problem can be formulated as an optimization problem with constraint conditions. In this paper, the following three topics are discussed: 1) an operating model of the apogee motor; 2) definition of the objective function for the optimization problem; and 3) the method of optimization. [passage omitted]

3. A Summary of the Optimization Procedure

The procedure for apogee motor control to achieve orbit change can be summarized as follows:

(1) Determine the transfer orbit;

(2) Calculate the nominal values t tilde, α tilde, and δ tilde;

(3) Determine the range and step size for choosing t, α, δ;

(4) For each set of t, α, δ, calculate the parameters a_s, e_s, i_s, Ω_s after engine cut-off;

(5) Calculate the objective function ΔV;

(6) Repeat steps (3)-(5) to find the values of t, α, δ which minimize ΔV;

(7) Choose t - 0.55T as the actual ignition time, and choose α, δ as the ignition attitude.

References

1. J. W. Cornelisse, H. F. R. Schoyer, and K. F. Wakker, "Rocket Propulsion and Spacecraft Dynamics," p 377.

2. Zhang Renwei, "Orbit and Attitude Control of Geostationary Satellites," Science Publishing House, 1987.

Matrix Method of Attitude Determination for Spin-Stabilized Satellite

91FE0134J Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 2, Apr 90 pp 16-24

[Article by Zhou Wenzhong [0719 2429 1813] of the Beijing Institute of Control Engineering; MS received 15 June 89]

[Excerpts]

Abstract

The matrix method of attitude determination for spin-stabilized communications satellite and the application of this method in seven different cases are described. This method uses the Earth angle θ_e, the sun angle θ_s and the rotation angle from the sun to the center of Earth λ_{se} to determine the attitude of a geosynchronous spin-stabilized satellite. The method is computationally simple, and provides a unique and accurate solution to the satellite attitude; the only geometric constraint of the solution is when the Earth vector and the sun vector become co-linear. This matrix method has been successfully applied and verified for five geosynchronous communications satellites launched by this country. [passage omitted]

II. Matrix Equations for Satellite Attitude[3,4]

[Passage omitted] Of the seven cases discussed above, case 1 is a regular case where the satellite attitude can be uniquely determined; cases 2, 3, 4, 5 are non-regular cases for which two ambiguous solutions exist; cases 6, 7 are also non-regular cases for which four ambiguous solutions exist. The following guidelines can be used to distinguish the true solutions from the false solutions:

(1) The sun angle θ_s and the Earth angle θ_e that fall within the sensor range and the measured λ_{se} in the immediate vicinity are true solutions.

(2) The solution which is close to the regular case 1 is a true solution.

(3) With multiple sets of attitude data, the average attitude with the smallest degree of dispersion is the true solution.

The results of satellite attitude determination show that the attitude (α, δ) obtained by a deterministic method is in close agreement with the attitude estimated by using the Kalman-filter method. Under normal operating mode, the determined spin axis of the satellite attitude points to the North, and δ falls within a 0.2° cone; more accurate North-pointing can be achieved by using precision control. [passage omitted]

V. Conclusion

The method described in this article provides a unique solution to the satellite attitude-determination problem. The singular conditions of this method are more relaxed than the constraint conditions of other two-measurement attitude determination methods; consequently, an expanded launch window can be accommodated. This method also provides higher accuracy than conventional two-measurement attitude determination methods because the angle λ_{se} can be readily introduced into the attitude filter to improve its accuracy. The method has been used in actual attitude determination during launch and during normal operation of China's communications satellites. The successful application of this method has demonstrated its validity and its practical value.

References

1. James R. Werez, "Spacecraft Attitude Determination and Control," D. Reidel Publishing Company, Dardrecht, Holland/Boston, 1978.

2. Cast Grubin, "Simple Algorithm for Intersecting Two Conical Surfaces," JOURNAL OF SPACECRAFT AND ROCKETS, 14 (1977), 251-252.

3. Zhou Wenzhong, Hu Zhicai, "Attitude Determination and Estimation for Geosynchronous Spin-Stabilized Satellites," 1980.8, First National Conference on Space Control Theory and Applications.

4. Zhou Wenzhong, Hu Zhicai, "A Method of Determining the Attitude of Geosynchronous Spin-Stabilized Satellites," ZIDONGHUA XUEBAO [ACTA AUTOMATICA SINICA], Vol 8, No 3, July 1982.

High-Reliability Traveling-Wave-Tube-Amplifier Power Supply

91FE0134K Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 2, Apr 90 pp 44-51

[Article by He Xianze [0149 6343 3419] of the Xian Institute of Space Radio Engineering; MS received 10 September 89]

[Excerpts]

Abstract

The power supply of the traveling-wave-tube amplifier (TWTA) used on the improved communications satellite DFH-2A is described. The power supply is directly connected to the solar cells without using a secondary voltage stabilizer. The basic function, design methods and test results of a double-winding-type energy-storage inductor are described in detail. The adverse effects of residual gas and particles of vaporized materials on the TWTA are pointed out and the methods of eliminating these gases are discussed.

I. Introduction

[Passage omitted] In order to bring China's communications satellites quickly to the operational stage, an effort was initiated in 1984 to develop an improved communications satellite.

In this new design, the Earth-coverage antenna is replaced by a domestic-coverage directional antenna with higher gain; the double-frequency-conversion transponder is replaced by a single-frequency-conversion transponder; the number of transponders is increased from two to four; and the original 8-watt TWTA is replaced by a 10-watt TWTA. Clearly, these new measures of increasing the EIRP and

communications capacity would result in increased mass and higher power consumption.

In order to accommodate this new design, significant improvements have also been made to the power supply of the TWTA. Specifically, to achieve higher utilization efficiency, the power supply is directly connected to the solar cells without using a voltage-regulated secondary power source. After four years of development and testing, the design goal has been achieved.

The improved TWTA has a mass which is 4.8 kg less than the original TWTA; it has also been successfully demonstrated on the two DFH-2A satellites launched on 7 March 1988 and 22 December 1988, respectively.

II. Block Diagram and Operation of the Power Supply

The block diagram of the improved TWTA power supply is shown in Figure 1; its operation will be briefly described below.

When a command is issued to turn on the TWTA power supply, the contact points of the relay J_3 are closed, which connects the voltage regulator and the solar cells and activates the 20-V power supply. At the same time, J_1 is also closed, and the filament converter begins energizing the filament of the TWT; the filament voltage reading is indicated by telemetry. Approximately 3 minutes later, the time-delay circuit of the switch control circuit closes the relay J_2, and the collector converter and the spiral-electrode converter begin applying high voltage to the electrodes of

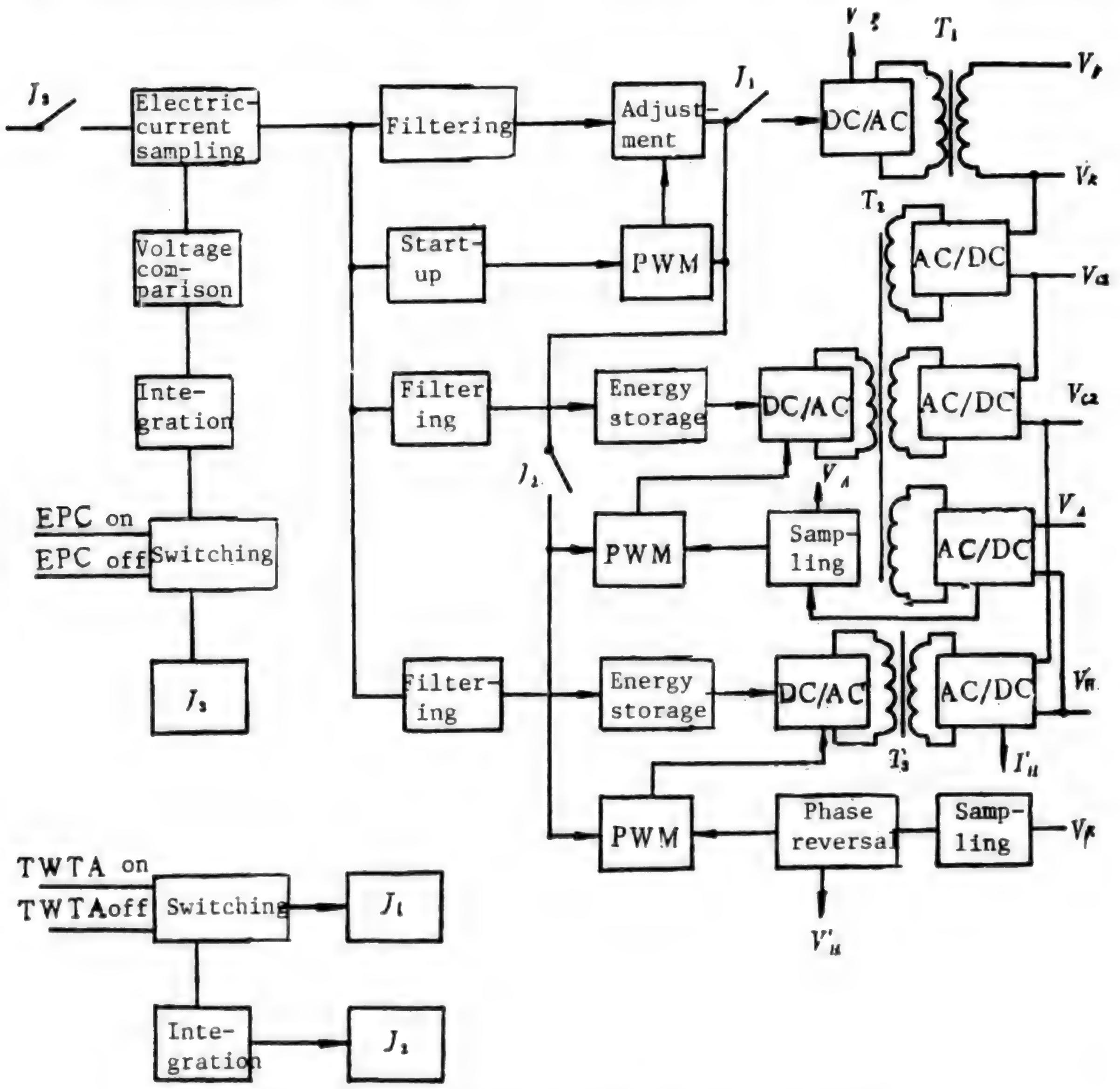

Figure 1. Block Diagram of the Traveling-Wave-Tube Power Supply

the TWT. At this point, telemetry readings indicate the presence of anode voltage, spiral-electrode voltage, and spiral-electrode current, and the TWTA is in a waiting state.

The ground television station and communications station transmit an uplink signal f_u to the satellite, which passes through the transponder and is re-transmitted as the downlink signal f_d.

A more detailed description of the major components of the block diagram will now be given.

1. The Switch and the Overcurrent-Protection Circuit With Transient Time Delay

The switching circuit uses a magnetic holding relay. The overcurrent protection circuit is provided to protect the primary power supply against excessive current caused by the occurrence of electric arcs and the failure of certain components in the power supply.

The high-voltage end of the TWTA power supply uses a capacitance filter and other switching elements. When the TWT is turned on, the input surge current may be 4-5 times higher than normal current level. In order to limit the threshold current and to ensure reliable operation, the overload protection circuit is equipped with an integral time-delay circuit.

2. Voltage Pre-Stabilizer

The voltage pre-stabilizer is used to pre-regulate the 24-41-V voltage from the solar cells to a steady 20-V source for the filament converter and other auxiliary units in the power supply. It consists of a fixed-frequency pulse-width modulation (PWM) Back-type converter and a starting circuit. When it is first turned on, the components are powered by the solar cells; when the pre-stabilizer begins operation, it generates its own power.

3. Filament Converter

The filament converter is a self-excited transformer-type DC/AC converter. In order to keep the TWT in optimum operating conditions and to maintain its electrical performance and prolong its service life, the filament transformer must be designed to match the specific type of TWT. The TWT should be powered by AC square waves whose frequencies are higher than 8 kHz in order to minimize carrier-frequency modulation by the induced voltage of the filament. Also, the primary stages of the filament transformer must be heavily insulated against high voltage.

4. Spiral-Electrode Converter

The spiral-electrode converter is an electric-current feedback-type high-voltage DC/DC converter; its input is directly connected to the solar cells. This converter requires a high degree of regulation of the output voltage.

5. Collector Converter

The collector converter also uses an electric-current feedback-type high-voltage DC/DC converter which is directly connected to the solar cells. This converter not only serves as a voltage transformer but also performs the function of voltage stabilization over a wide range. Its basic operation, design methods and effectiveness are described in Section III; a detailed discussion of the converter can also be found in Ref. 2. Because of the large output power of the converter, strict requirements are imposed on the selection of the switching units, the design of the energy-storage inductance, the fabrication of the high-voltage transformer, the storage of the high-voltage silicon bridges, and the reverse recovery time.

III. High-Voltage Converter

In this design, both the spiral-electrode converter and the collector converter use the electric-current feedback-type high-voltage DC/DC converter. Its operation is illustrated by the diagram shown in Figure 2.

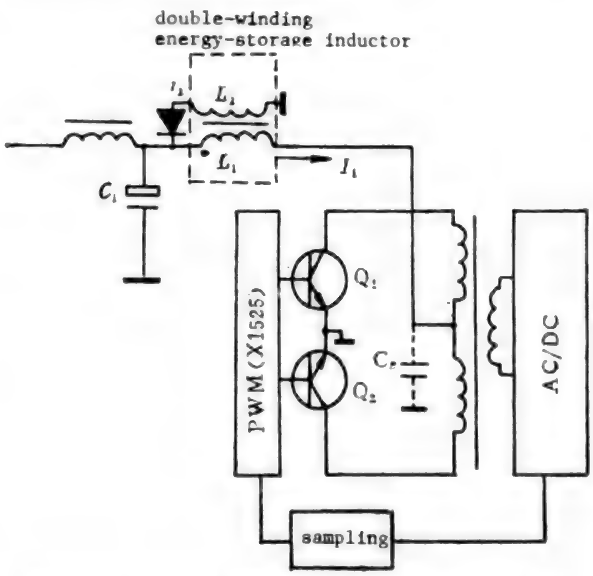

Figure 2. Diagram Illustrating the Operation of the High-Voltage DC/DC Converter

The main difference between this converter and the conventional push-pull type DC/DC converter is the PWM excitation and energy recovery system. This added circuit can control the output of the converter including the voltage level of the TWT. When the output voltage V_o exceeds a certain value V_{o1}, the error amplifier will change the pulse width of the PWM, thereby reducing V_o to keep it at a constant level.

When the two switches are both in the off position, the electric current I_1 in the inductance L_1 is cut off, and the voltage on L_1 is reversed. Because of the effect of feedback, a voltage V_{L2} given by: $V(L_2) = V(L_1) \times (N_2/N_1)$ exists on L_2; it is equal to V_C plus the positive voltage drop of the diode. At this time, I_2 begins to flow. When the next cycle of base excitation arrives, I_2 is cut off and I_1 begins to flow.

The output voltage, input voltage and the null ratio are given by the following relations:

The electric current I_1 flowing through L_1 is

$$I_1 = \frac{1}{L_1}\int_0^T (V_C - V_R)\,dt + I_0 \qquad (1)$$

Applying the differential equation

$$\Delta i_1 = \frac{V_C - V_R}{L_1} \cdot t_{on} \qquad (2)$$

and the principle of energy conservation, we have:

$$V_C I_1 t_{on} = V_R I_1 t_{on} + V_C I_2 t_{off} \qquad (3)$$

$$V_R/V_C = \frac{I_1 t_{on} - I_2 t_{off}}{I_1 t_{on}} = 1 - \frac{I_2 t_{off}}{I_1 t_{on}} \qquad (4)$$

$$I_2/I_1 = N_1/N_2 \qquad (5)$$

If $N_1 = N_2$, then

$V_R/V_C = 1 - t_{off}/t_{on}$ (6)

Because the electric-current feedback PWM-type high-voltage DC/DC converter performs the dual functions of voltage conversion and stabilization, it does not require a secondary power source, and therefore the additional mass and power consumption are eliminated.

The pulse width modulator can be designed using a magnetic amplifier[3] or using separate components.[1]

The energy-recovery system consists of the following elements: the double-winding energy-storage inductor X, the reflected capacitance C_R reflected from the secondary stage to the primary stage, the diode CR and the capacitance C_1.

The secondary feedback coil of the energy-storage inductor can be connected to either the primary stage or the secondary stage, as shown in Figure 3. In the case of low-voltage output, it is connected to the secondary stage; for high-voltage output, it is connected to the primary stage.

In the present design, the feedback winding is connected to the primary stage, as shown in Figure 4.

The basic operation of the energy-recovery system is as follows:

The inductance L_1 and the capacitance C_R, which is reflected onto the primary stage of the high-voltage

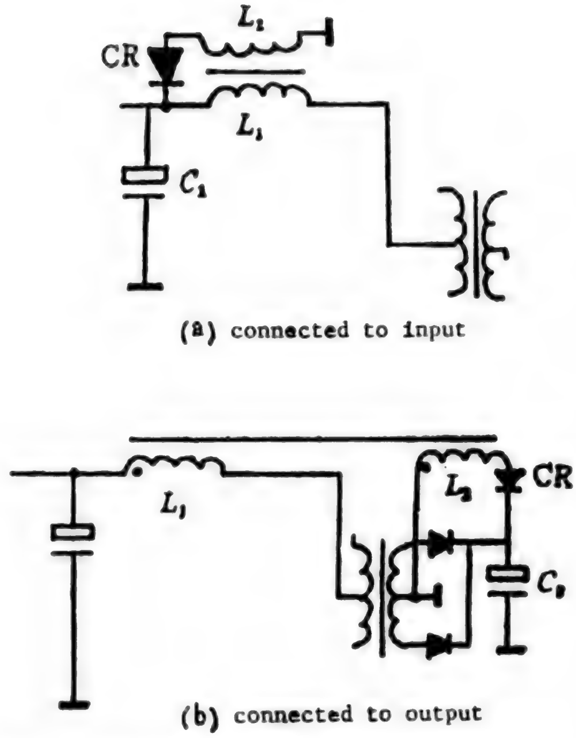

Figure 3. Two Methods of Connecting the Feedback Coil of the Energy-Storage Inductor

transformer by the output capacitance, form an LC smoothing filter network that is an essential element for any switched voltage-regulated power supply. The energy-recovery system is composed of the elements L_1, L_2, C_1, CR and C_R. Q_1 and Q_2 are idealized switching elements. When the switch Q_1 (Q_2) is in the "on" position, $i_2 = 0$, $I_{in} = I_1$, and the energy stored in the inductor is equal to $(V_C I_1 - V_R I_1)t_{on}$; when the switch Q_1 (or Q_2) is in the "off" position, $I_1 = 0$, the stored energy is returned by the inductor and transferred to the capacitance C_1 by the energy-recovery system. During the switch "off" period, $I_{in} = -i_2$; if the positive voltage drop of the diode and losses of the other components are neglected, then the energy should be equal to $V_C i_2 t_{off}$, or $L_1 \Delta i_1 I_1$, where I_1 is the average value of i_1 during the "on" period.

Figure 5 [photo not reproduced] shows the waveforms at different points of the electric-current feedback PWM-type high-voltage DC/DC converter and the variation of pulse width with input voltage.

By using the energy-storage inductor, the PWM-type high-voltage DC/DC converter not only performs voltage stabilization and conversion, but also provides improved efficiency with respect to variations in the input voltage.

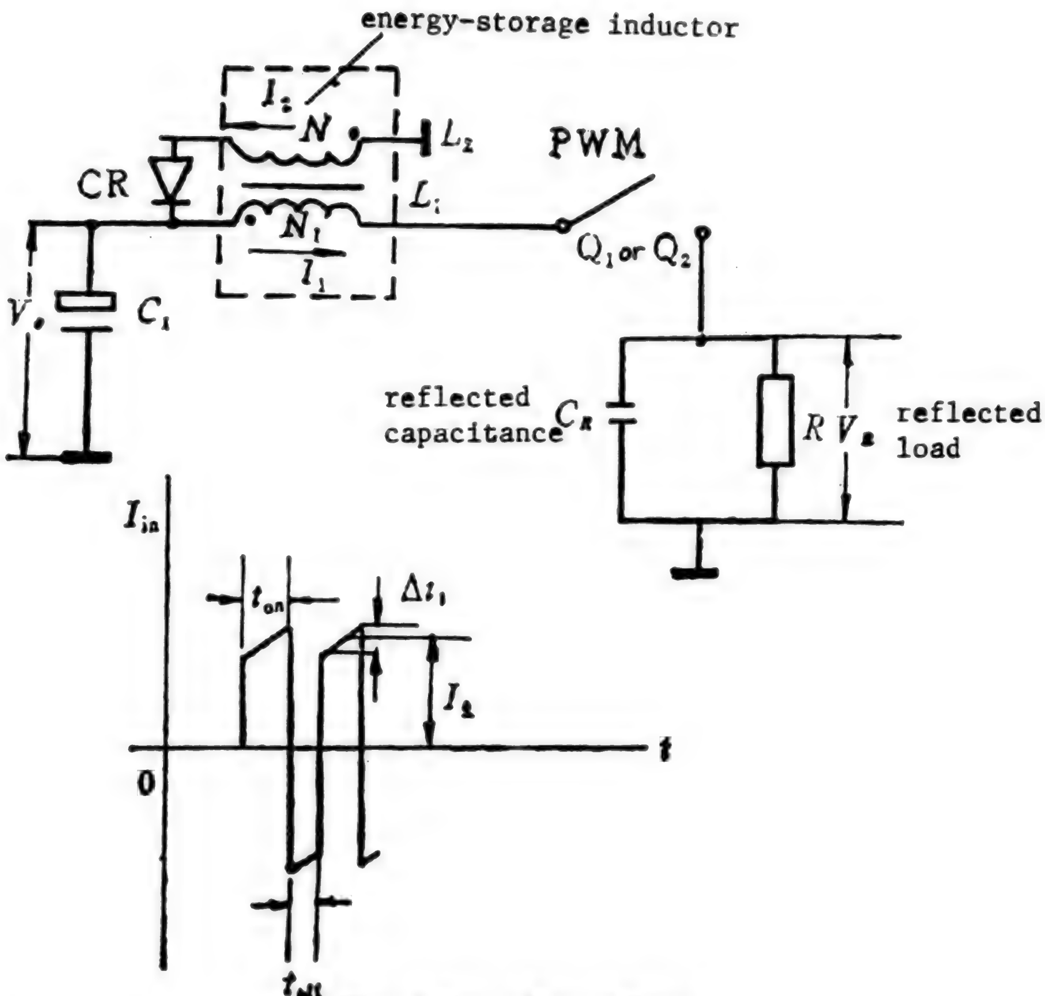

Figure 4. Energy-Recovery System

Table 1. Improved Electric Efficiency Using the Double-Winding Energy-Storage Inductor

Input voltage	24 (V)		28 (V)		32 (V)		36 (V)		41 (V)	
	With inductor	Without inductor	With inductor	Without inductor	With inductor	Without inductor	With inductor	Without inductor	With inductor	Without inductor
Input current (A)	1.55	1.55	1.35	1.55	1.22	1.55	1.11	1.35	1.02	1.55
Input power (W)	37.2	37.2	37.8	43.3	39.04	49.6	39.96	55.8	41.8	63.55
Output power (W)	28.38	28.38	28.39	28.38	28.38	28.38	28.38	28.38	28.38	28.38
Efficiency	76%	76%	75%	65%	72.8%	57.2%	70%	50.8%	67.8%	44.6%

IV. Corona-Resistant Design

Since the TWTA's of China's communications satellites are used as amplifiers for both communications and telemetry transponders, they must begin operation as soon as the satellite is launched. The TWTA's of foreign satellites, on the other hand, are turned on only after reaching geosynchronous orbit. For this reason, a series of special measures are necessary in designing the power supply.

As a TWTA is a high-voltage electric device which uses air as the medium, a close relationship exists between the breakdown potential of air and the voltage and air pressure between the electrodes, as given by Parson's curve. When the product of air pressure P (in Pascals) and the distance between electrodes d (in cm) is 67, the breakdown potential is 300 V. Therefore, when the voltage between electrodes is greater than 300 V and the gas pressure is in the dangerous zone, breakdown is inevitable. Figure 6 shows a plot of Parson's curve.

To avoid electric breakdown when the gas pressure is in the dangerous zone, the following design approaches are adopted. For high-voltage electric equipment operating

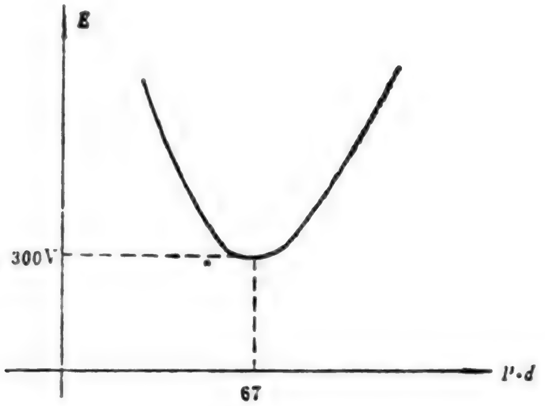

Figure 6. Parson's Curve

at low altitudes over relatively short durations, electric breakdown can be avoided by simply enclosing the equipment in a sealed compartment. However, this method is inadequate for equipment operating at high altitudes over long durations. For high-voltage equipment which is turned on only at geosynchronous altitude, one can use a vacuum as the insulating medium; but sufficient ventilation must be provided in the structural design for all the gas particles to escape from the unit during the transfer orbit. The organic insulating material must have a very low gasification rate and low volatility to avoid accumulation of gas particles between the electrodes which may create conditions for electric discharge similar to those of dangerous gas pressure. The TWTA's of China's communications satellites use resin in place of air as the insulating medium to avoid dangerous gas pressure.

The high-voltage transformer design must provide good electric field distribution, and the voltage at the high-voltage winding must not exceed 1 kV; the transformer must be first vacuum-sealed with silicon gel, which is then solidified under pressure. The transformer must be tested for corona starting voltage, and the voltage must be greater than 1.5 times the operating voltage. Table 2 shows the corona starting voltages and operating voltages of three collector transformers.

Table 2. Corona Starting Voltage

Transformer No.	Corona starting voltage	Operating voltage of winding
1-<I>	2 kV	500 V
1-<III>	3.4 kV	550 V
1-<V>	2.7 kV	800 V

Other high-voltage components and circuits are also sealed with silicon gel, and the corona starting voltages between the electrodes are measured.

The residual gas and gasified particles from insulating materials can be very damaging to spaceborne TWTA's. If gas bubbles are present in the insulating materials, then according to the theory of corona discharge, the field strength in the gas bubbles would be greater than the field strength in the insulating material. The resulting corona in the gas bubbles will cause the resin to be carbonized, and over time a closed circuit will be formed between the electrodes, creating electric arcs and causing permanent damage to the material.

If resistors and wiring columns with cavities are used in the high-voltage circuits, corona may also occur due to the presence of residual gas.

To avoid a high-voltage electric field, the potential gradient in the high-voltage circuit must be sufficiently small to ensure gradual drop in the voltage distribution; also, sharp edges and points should be avoided. For example, for a spherical electrode with a radius of curvature of 1 cm, the electric field strength is 200 V/cm; if the inter-electrode distance remains unchanged but the radius of curvature is reduced to 1 mm, then the field strength becomes 20,000 V/cm. Therefore, the weld points in a high-voltage circuit must be smooth, and the radius of curvature of the electrode must be large.

V. Other Improvements

In addition to major improvements in power delivery and in corona resistance, other improvements have also been made in the TWTA's of China's communications satellites.

1. Overcurrent Protection Circuit

The basic principle of the integral time-delay overcurrent protection circuit has been briefly described in Section 2. In design implementation, a storage oscilloscope is used to measure the waveform of the surge current when the TWTA is turned on, and its threshold current and threshold time are determined, as shown in Figure 7. A block diagram of the circuit design is shown in Figure 8.

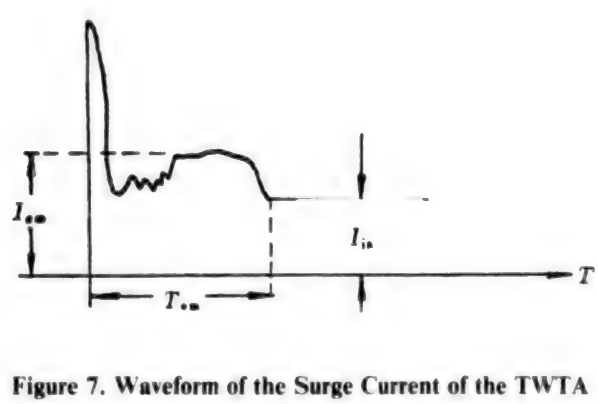

Figure 7. Waveform of the Surge Current of the TWTA

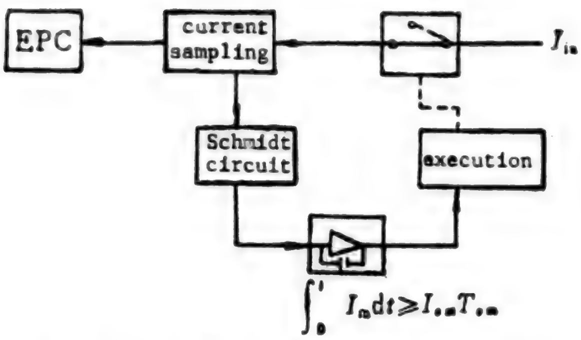

Figure 8. Integral Time-Delay Overcurrent Protection Circuit

2. Improved Design of the High-Voltage Anode Circuit

In order to simplify the design of the high-voltage converter, a voltage divider is used to provide different anode voltages, as shown in Figure 9.

$$V_A = V_{A0}\frac{R_2+R_3}{R_1+R_2+R_3}$$

The disadvantage of this circuit is that the anode circuit has very high output impedance, and the anode voltage is strongly affected by the anode current. Also, when the unit is first turned on, a pulse voltage is generated, which may cause open circuit in R_1. This difficulty can be overcome by designing the collector transformer to match the anode voltage of the TWTA, so that $V_{A0} = V_A$, $R_1 = 0$; such a design will reduce the output impedance of the anode circuit and improve the stability of the anode voltage, and consequently minimize the effect of fluctuations in anode current on the anode voltage.

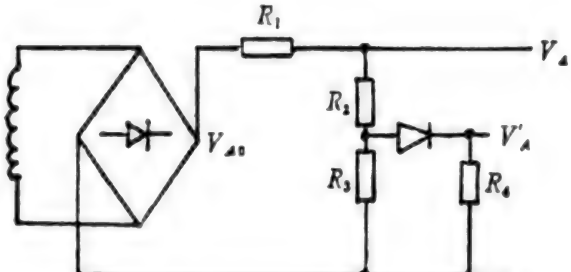

Figure 9. Anode Circuit

References

1. Boyd P. Israelsen, James R. Martin, et al., "A 2.5 kV High-Reliability TWT Power Supply, Design Techniques for High Efficiency and Low Ripple," PESC, 1977.

2. V. Joseph Thottuvelil, Thomas Wilson, Harry A. Owen, Jr., "Analysis and Design of a Push-Pull Current-Fed Converter," PESC, 1981.

3. He Xianze, Yin Xiankui, "Methods for Designing TWT Power Supply for Communications Satellite," KONGJIAN DIANZI JISHU [SPACE ELECTRONIC TECHNOLOGY], February 1982.

Antenna System for DFH-2A Satellite

91FE0134L Beijing ZHONGGUO KONGJIAN KEXUE JISHU [CHINESE SPACE SCIENCE AND TECHNOLOGY] in Chinese Vol 10 No 4, Aug 90 pp 36-43

[Article by Chen Zhiyuan [7115 1807 6678] of the Xian Institute of Space Radio Engineering]

[Excerpts]

Abstract

This paper describes a mechanically despun satellite antenna system for domestic telecommunications service. The antenna system consists of three parts: an omni-directional telemetry, command and control antenna assembly, a directional communications antenna, and a three-channel non-contact rotary joint. The telemetry, command and control antenna is a dual-disk antenna with omni-directional beam pattern and circular polarization. The communications antenna is an offset elliptical paraboloid antenna with single-horn feed for both transmitting and receiving. It generates a 5° x 8° elliptical beam which provides proper coverage over the Chinese mainland. The three-channel non-contact rotary joint has a concentric triple coaxial line structure which forms three transmission channels. There are chokes at the rotary joint of each coaxial line. The insertion loss of each channel is 0.6-0.8 dB, and the isolation between channels is greater than 50 dB.

I. Introduction

The "DFH-2" communications satellite used a mechanically despun global-coverage antenna which covers the Chinese mainland and surrounding oceans to provide wide-area communications. To satisfy the urgent needs of domestic communications, another communications satellite, the "DFH-2A" was successfully launched in March 1988; the antenna beam of the "DFH-2A" covers only the Chinese mainland to provide enhanced EIRP and communications capacity. Its antenna design is based on the following requirements and conditions: the satellite position is between 87.5°E and 110.5°E; the antenna beam has an elliptical pattern covering the Chinese mainland; the uplink frequency is between 6055 MHz and 6421 MHz, and the downlink frequency is between 3830 MHz and 4196 MHz; the satellite is spin-stabilized, and the antenna system is mechanically despun.

II. Basic Considerations of the Antenna Design

The communications antenna is an offset elliptical paraboloid antenna for both transmitting and receiving. This antenna has a relatively high efficiency with no aperture blockage; also, its low center of gravity is well suited for a spin-stabilized satellite. The telemetry, command and control antenna is a dual-disk antenna with a circular waveguide slot feed; this antenna has a good omni-directional beam pattern, and can be used before the satellite is completely stabilized. To despin the antenna, a three-channel non-contact rotary joint with high degree of isolation has been developed.

III. Basic Operation of the Antenna System and the Electrical Block Diagram

The antenna system of the "DFH-2A" satellite consists of three parts: the omni-directional telemetry, command and control antenna, the directional communications antenna, and the three-channel rotary joint; in addition, it also contains the frequency synthesizer, the feed waveguide and the electric cables that connect the different parts.

The electrical block diagram is shown in Figure 1. The downlink telemetry signal from the transponder is fed in through terminal 1 of the rotary joint, and passes to terminal 1' which is connected to the output telemetry antenna. The downlink communications signal is fed in through terminal 2, passes through the rotary joint to the output terminal 2', and fed to the orthogonal (i.e., quadrature) mode converter of the communications antenna; finally it is radiated by the paraboloid reflector toward the earth to be received by the ground receiving station. The uplink command signal and communications signal received by the telemetry antenna and paraboloid antenna are fed to the frequency synthesizer, then

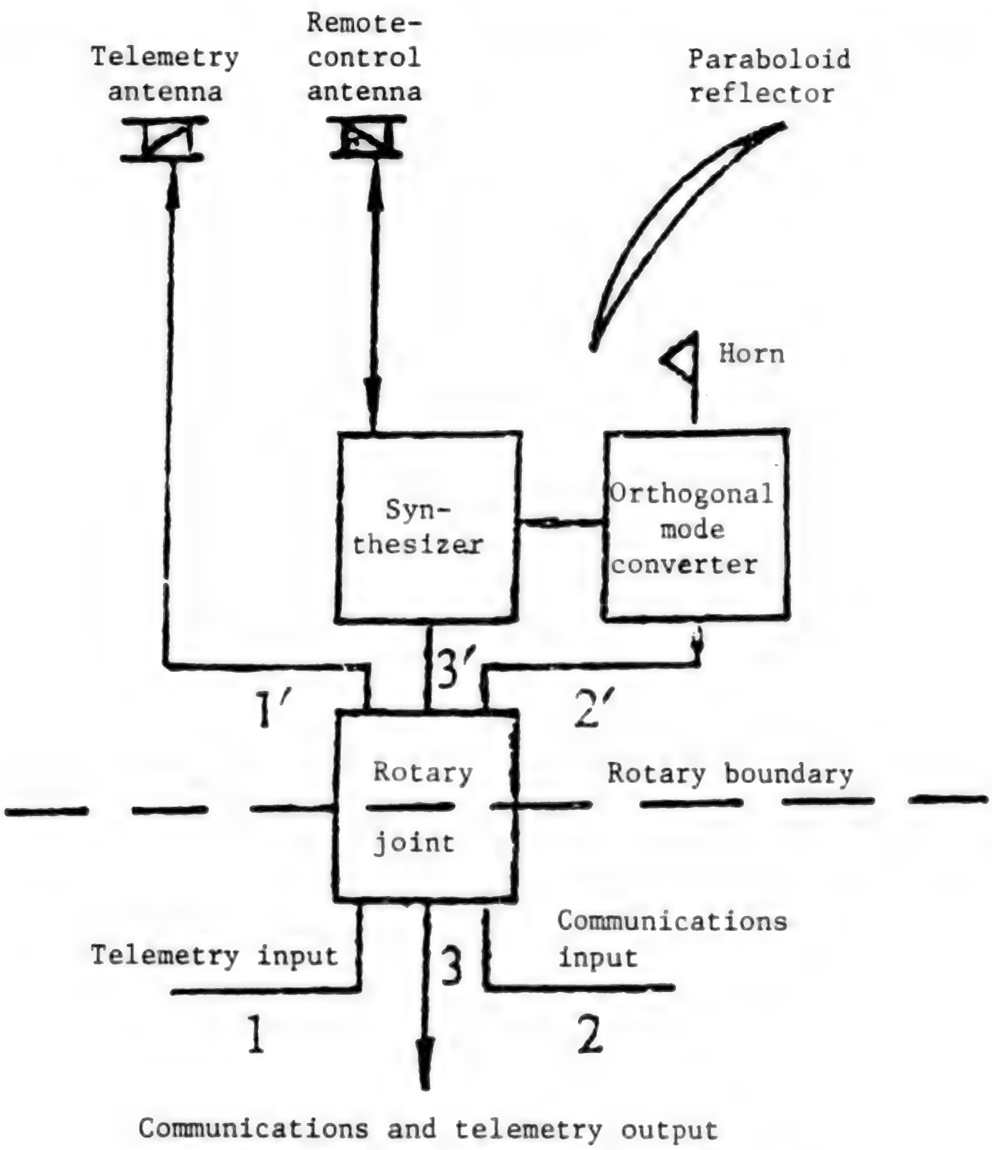

Figure 1. Electrical Block Diagram of the Antenna System

through the common terminal of the synthesizer to terminal 3' of the rotary joint; the signal passes through the rotary joint to terminal 3 for output to the receiving duplexer of the transponder.

IV. Elliptical-Aperture Offset Paraboloid Antenna for Both Transmitting and Receiving

By using a truncated elliptical-aperture offset paraboloid antenna (for transmitting and receiving communications signals), it is possible to generate an effective elliptical beam pattern while keeping the antenna mass relatively small.

1. Requirement for Beam Coverage of the Chinese Mainland

Consider a satellite in geosynchronous orbit; if one constructs a sphere centered at the antenna, and projects the shape of the Chinese mainland onto the sphere, then the profile on the sphere is the required beam shape to cover the mainland. This projected shape changes somewhat with different satellite positions. Figure 2 shows the calculated profile of the Chinese mainland at a satellite position of 87.5°. If we draw an ellipse that envelops the profile, then this ellipse represents the approximate beam shape that covers the mainland. It can be seen from Figure 2 that a 5° x 8° elliptical beam provides adequate coverage of the mainland. The peak gain of the beam occurs at the center of the ellipse, and the gain value of the edge ellipse is generally 3-4 dB lower than the gain at the center.

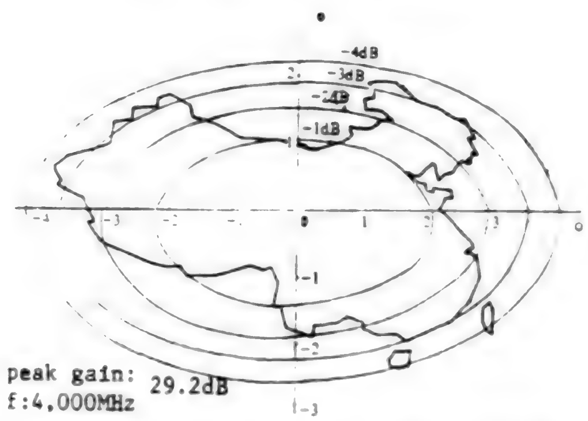

Figure 2. Beam Coverage of the Chinese Mainland

If the sidelobe of an offset paraboloid antenna does not exceed -20 dB, then the projected aperture size can be calculated from the following expression:

$$D = 1.15\,\lambda/\theta \qquad (1)$$

where λ is the wavelength and θ is the half-power beamwidth.

This equation provides an initial estimate of the projected aperture of the paraboloid, which is also taken to be the aperture of the ellipse; the major axis of the ellipse is 1.3 m, and the minor axis is 0.62 m. To reduce the antenna height, the ellipse is truncated at both ends, as shown in Figure 3.

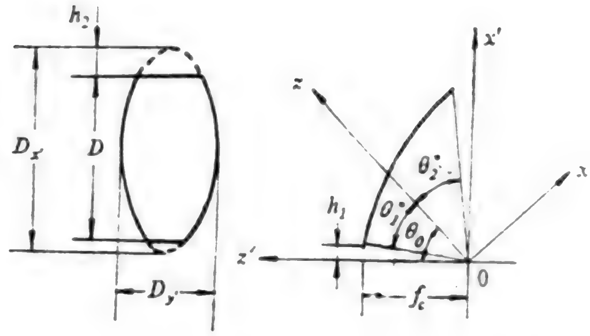

Figure 3. Schematic Diagram of the Truncated Elliptical Paraboloid

The offset paraboloid antenna consists of the truncated elliptical paraboloid, the feed horn, the orthogonal mode converter and the feed waveguide. The configuration of the antenna system (including the telemetry, command and control antenna and the rotary joint) is shown in Figure 4. The axis of the antenna system is tilted 5.5° relative to the spin axis of the satellite so that the peak of the beam points 5.5° to the north toward the Chinese mainland.

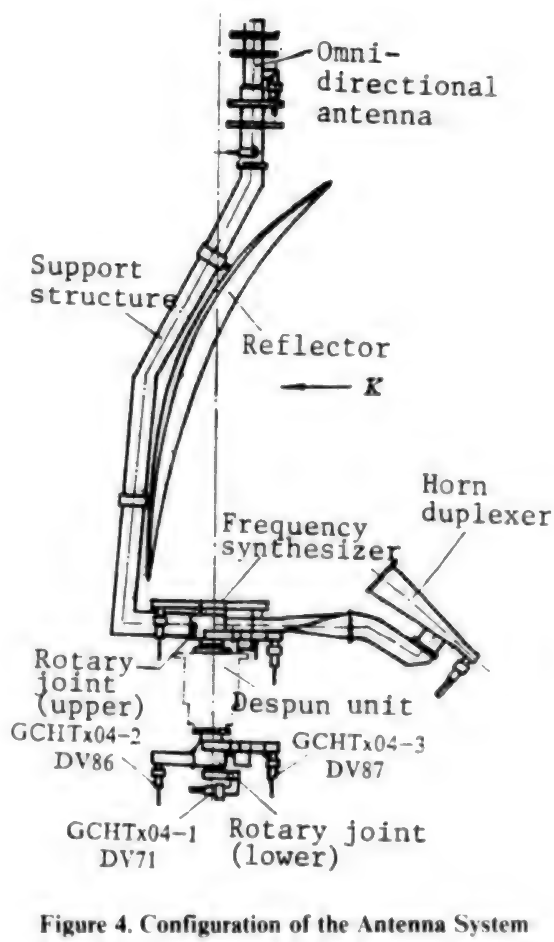

Figure 4. Configuration of the Antenna System

The parameters of the paraboloid are as follows: D = 1050 mm, $D_{y'}$ = 620 mm, $D_{x'}$ = 1300 mm, f_c = 650 mm; $\theta_0 = 45°$, $\theta^*_1 = 40.6°$, $\theta^*_2 = 35.5°$, h_1 = 50 mm, h_2 = 200 mm. The edge opening angle in the yz plane is $2\theta_3 = 45.3°$. The feed is a conical horn whose dimensions are 96.2 mm x 120 mm; its narrow side is parallel to the x-axis and its broad side is parallel to the y-axis; the focal point is located at the center of the aperture. The half angles of the horn are respectively 7.7° and 15.9°. For the downlink frequency, the polarization is parallel to the broad side; for the uplink frequency, the polarization is parallel to the narrow side. The downlink excitation is achieved through the longitudinal slot located on the side of the conical horn, and it is coupled to the BJ-40 waveguide; the uplink excitation is achieved through the BJ-58 waveguide located on top of the horn.

2. Gain, Efficiency and Beam Contours of the Offset Paraboloid Antenna

[Passage omitted] The calculated pattern of the feed horn, taking into consideration space loss and edge illumination (relative to $\theta = 0$), yields the following results: for the downlink center frequency, it is -7.3 dB ($\theta^* = 40.6°$) and -10 dB ($\theta^* = 35.5°$) in the xz plane, and -6.6 dB in the yz plane; for the uplink center frequency, it is -9.4 dB in the yz plane. However, in the xz plane, the aperture efficiency is reduced because the illuminated region is occupied by sidelobes. [passage omitted]

The measured antenna peak gain is 29.2 dB for the downlink center frequency and 31 dB for the uplink center frequency. The efficiency η is 0.67 for the downlink and 0.42 for the uplink. The measured beam contours are shown in Figure 2. Since the feed horn is designed based on the downlink frequency, the aperture efficiency for the uplink is much lower; the uplink coverage contours are approximately circles rather than ellipses.

V. Omni-Directional Telemetry, Command and Control Antenna

The telemetry, command and control antenna must meet the following requirements: broad beam pattern in the meridian plane and omni-directional pattern in the equatorial plane; and circular polarization. An antenna that meets this requirement is the dual-disk antenna, as shown in Figure 5. The telemetry antenna and the command and control (i.e., remote-control) antenna are coaxially installed. Each antenna is made of two parallel disks, at the center of which are the circular feed waveguides that excite the circularly polarized waves. Along the circumference of the circular waveguide are eight uniformly spaced 45°-inclined slots which provide excitation in the radial direction. Two types of waveforms are propagated inside the radial waveguide: one is the TE_{10} waveform whose polarization is parallel to the disk surface, the other is the TEM waveform whose polarization is perpendicular to the disk surface. In order to achieve a broad beam pattern in the meridian plane, the disk spacing should be as small as possible while still keeping the TE_{10} waveform from being cut off. The diameter of the circular disk is chosen based on circular polarization considerations. The TE_{10} waveform and the TEM waveform excited by the inclined slots are of equal amplitude; they propagate along the radial direction of the disk with different phase velocities, and by the time they reach the aperture, the two polarizations differ in phase by 90°, thus forming a circularly polarized wave. The telemetry antenna has left-hand circular polarization (LHCP), and the command and control antenna has right-hand circular polarization (RHCP).

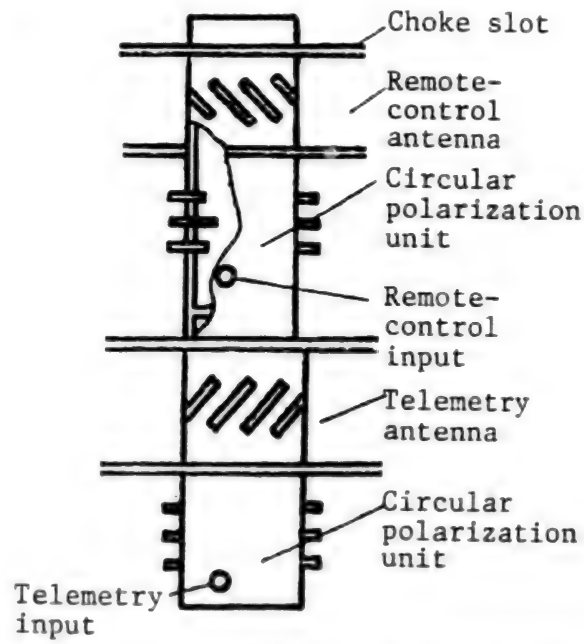

Figure 5. Schematic Diagram of the Telemetry, Command and Control Antenna

The phase constant of the TE_{10} waveform is $2\pi/\lambda_g$, and the phase constant of the TEM waveform is $2\pi/\lambda_0$; the phase difference at the aperture is

$$\Delta\varphi = (2\pi/\lambda_0 - 2\pi/\lambda_g)l$$

Let $\Delta\varphi = \pi/2$, then the length of the disk is

$$l = \frac{\lambda_0}{4\left[1 - \sqrt{1 - \left(\frac{\lambda_0}{2a}\right)^2}\right]}$$

where a is the disk spacing.

In order to avoid spurious radiation from the outside wall of the circular disk, a quarter-wavelength choke slot is placed along the edge of the disk. To achieve orthogonal polarizations between radiations from the telemetry antenna and the command and control antenna, the directions of the inclined slots of the two antennas are

also orthogonal. The calculated and empirically adjusted disk diameter is 150 mm for the telemetry antenna and 127.7 mm for the command and control antenna.

In order to obtain an omni-directional beam pattern in the equatorial plane, the feed waveguide must excite circularly polarized waves. It is known that for a circularly polarized wave in a circular waveguide formed by two spatially orthogonal TE_{11} waveforms with a phase difference of 90°, the short-circuit current on the waveguide wall is[3]:

$$J_\varphi = jA \exp(-j\varphi) \sin K_{11} (z - z_0)$$

$$J_z = - B \exp(-j\varphi) \cos K_{11} (z - z_0)$$

where z_0 is the distance between the short-circuit point and the center of the slot.

It is clear that the current amplitudes of the inclined slots along the circumference are uniform in the φ direction, whereas the phases are progressive; consequently, a uniform radiation pattern in the φ direction is obtained. On the basis of structural considerations, the z_0 values for the telemetry antenna and the command and control antenna are chosen to be 72.2 mm and 65.9 mm respectively. When the inclined slot is a half-wavelength long and 3 mm wide, the voltage standing wave ratio is smaller than 1.10.

In order to form a circularly polarized wave in a circular waveguide where only the base mode TE_{11} is propagated, three pairs of pins are inserted symmetrically into the waveguide.[4] When the electric field passes through the pins at a 45° angle, the component parallel to the pins lags behind the vertical component due to the susceptance effect of the pins; when the phase lag is 90°, a circularly polarized waveform is formed inside the waveguide. The equivalent circuit for the component parallel to the pins and the pin susceptance is shown in Figure 6. The requirement on pin susceptance is

$$\frac{B}{Y_0} = \frac{\sin(2\beta l) - \cos 2\beta l}{\sin^2 \beta l}$$

$$\frac{B'}{Y_0} = \frac{\cos\beta l - \sin\beta l}{\sin\beta l \cos 2\beta l}$$

where β is the phase-shift constant and Y_0 is the characteristic admittance.

When $0.8 < \lambda_0/\lambda_c < 0.9$, satisfactory bandwidth can be achieved by choosing l equal to $0.25\ \lambda_c$. For the telemetry antenna, 2R = 54 mm, l = 23 mm, B/Y_0 = 1.73, B'/Y_0 = 0.83; for the command and control antenna, 2R = 46 mm, l = 19.5 mm, B/Y_0 = 1.73, B'/Y_0 = 0.83. B/Y_0 and B'/Y_0 are measured by inserting the pins into the waveguide.

The fluctuations in the measured beam patterns of the telemetry, command and control antenna in the equatorial plane are less than 1.5 dB; the gain of the measured pattern within a +/-30° range in the meridian plane is higher than -3 dB. However, when the antenna is installed on the satellite, the effect of the communications antenna and the satellite structure will cause slight changes in the pattern and produce higher fluctuations.

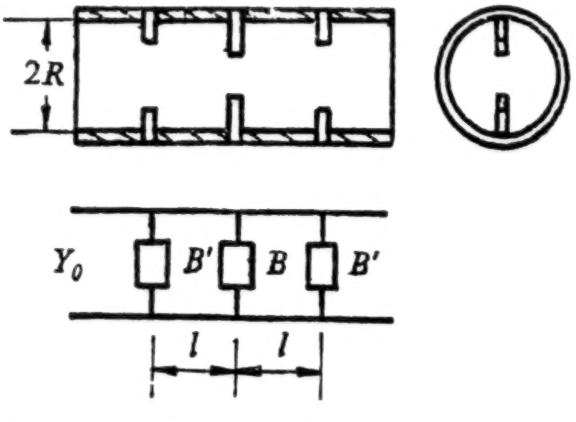

Figure 6. Three-Pin Circular Polarization Unit and Its Equivalent Circuit

VI. Three-Channel Rotary Joint

The outputs of the three-channel rotary joint are connected to the high-gain communications antenna and the low-gain telemetry, command and control antenna; therefore, a high degree of isolation between the channels is extremely important. In addition, because of vacuum cold welding, choke slots are used to provide electrical continuity between the rotary joints without mechanical contact.

When the feed current to the telemetry antenna passes through the rotary joint, part of the energy is coupled to the communications channel, which is radiated at the same frequency through the communications antenna, causing interference to the telemetry antenna pattern. Let E_0 and E_d be the radiated field strengths from the telemetry antenna and the communications antenna respectively; when E_0 and E_d have the same direction but differ in phase by 180°, the two fields cancel each other and create a depression in the pattern; when they have the same direction and the same phase, the two fields reinforce one another and create a bulge in the pattern. The gain variations of the antenna pattern can be calculated from the following expression:

$$\Delta G = 20 \log [(E_0 +/- E_d)/E_0]\ (dB)$$

where the plus sign applies to the case of zero phase difference and the minus sign applies to the case of a 180° phase difference.

If the two fields have the same linear polarizations, then the gain of the communications antenna would be 28.5 dB, and the gain of the telemetry antenna would be -3 dB; the isolation between the joints would be 50 dB. During operation of the telemetry antenna, the gain of the depression point in the antenna pattern would drop

by 1.1 dB, and the gain of the bulge point would rise by 0.97 dB; also, fluctuations in the antenna pattern would increase. A similar situation would exist during operation of the communications antenna. In practice, the telemetry, command and control antenna radiates circularly polarized waves, and the radiated field intensities of the two antennas are different; therefore, while the interference effect between the two antennas is complicated, it is less severe than the calculated results as indicated above. Nevertheless, to minimize fluctuations in the beam pattern of the telemetry, command and control antenna due to interference, the isolation between the telemetry channel and the communications channel should be greater than 50 dB. For the telemetry channel, the degree of isolation is determined by the rotary joint; for the command and control channel, the degree of isolation is determined by the synthesizer.

In order to achieve a high degree of isolation, the rotary joint has a three-layer, concentric coaxial design, as shown in Figure 7. Channel 1 is the center coaxial line, which is the receiving channel for the uplink command and control signal and the communications signal; it is made of a coaxial cable with an inner/outer diameter ratio of φ3/φ7; the top input end has an L_{16} standard connector, and the bottom output end has a BJ-58 coaxial waveguide. Channel 2 is the mid-layer coaxial line, whose inner/outer diameter ratio is φ12/φ27.6; it is the downlink communications channel whose output is connected directly to the feed of the paraboloid antenna. Both the input and output terminals have BJ-40 waveguides. In order to match the high-impedance waveguide with the low-impedance coaxial lines, a ridge waveguide is used in the transition section to achieve the desired wideband characteristics. The impedance of the coaxial line is 50 Ω; only TEM waveforms are propagated inside the coaxial line to ensure symmetry of the electric field. This is essential to avoid signal fluctuations when the joints are rotating. Channel 3 is the outer coaxial line whose inner/outer diameter ratio is φ33.6/φ52; it is the downlink telemetry channel whose output is connected directly to the telemetry antenna. This coaxial cable has an inner conductor with a large outer diameter and an outer conductor with a large inner diameter; also, both TEM and TE_{11} waveforms can be propagated inside the cable. In order to preserve the symmetry of the electric field which may be destroyed by high-order waveforms, a BJ-48 waveguide Magic T is used at both input and output terminals to provide symmetric inphase feed. The two arms of the Magic T in the H-plane are connected symmetrically to the coaxial line, where only TEM waveform is excited; the arm of the Magic T in the E-plane is connected to the matched load to absorb high-order waveforms. The design of the choke slots uses all quarter-wavelength open circuits. The system performance of the rotary joints is shown in Table 1.

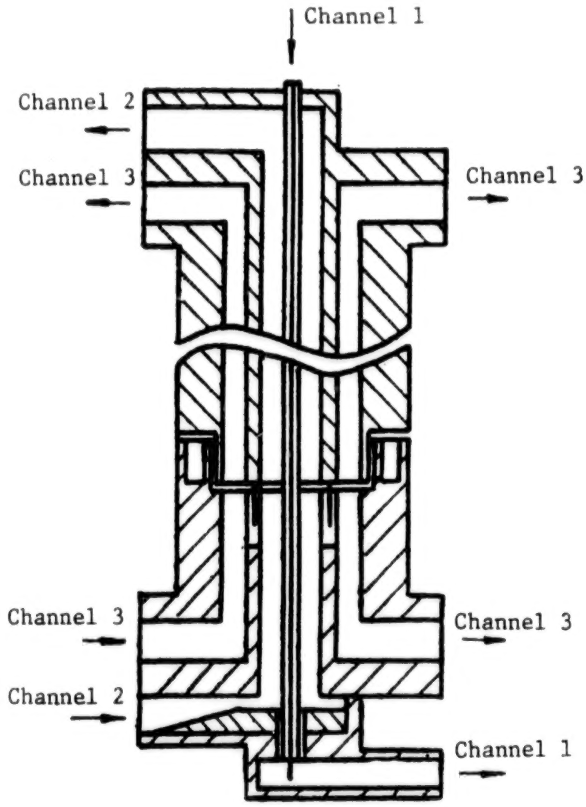

Figure 7. Schematic Diagram of the Three-Channel Rotary Joint

Table 1. Measured Performance of the Rotary Joint

Channel	Frequency (MHz)	Insertion loss (dB)	Isolation (dB)
1	5925-6425	<0.6	
	C-band point frequency	0.9	
2	3700-4200	<0.7	>50 (2-1)
3	C-band point frequency	0.8	>51 (3-2), >57 (3-1)

VII. On-Orbit Performance of the Antenna System

The measured performance of the antenna system is shown in Table 2 and Table 3.

Table 2. Measured Performance of the Communications Antenna System

Frequency (MHz)	3825	3848	3928	4098	4178	4200	6050	6073	6153	6323	6403	6425
Peak gain (dB)	29	29.1	29.5	29.7	29.7	30.2	30.7	30.8	31.2	30.9	31.7	31.5
Edge gain (dB)	>25	>25	>25	>25	>25	>25	>23.7	>23.5	>23.4	>23.4	>23.7	>23.5
Feed cable loss (dB)	0.9	0.73	1	1.05	0.9	1.3	1	1.15	1.4	1.9	1.65	1.6

Table 2. Measured Performance of the Communications Antenna System (Continued)

Frequency (MHz)	3825	3848	3928	4098	4178	4200	6050	6073	6153	6323	6403	6425
Despun gain fluctuation (dB)	0	0	0	0	0	0	0	0	0	0	0	0
Isolation between transmitting and receiving (dB)	>55	>56	>57	>56	>55	>50						
Polarization (linear polarization)	Polarization perpendicular to the spin axis						Polarization parallel to the spin axis					

Table 3. Measured Performance of the Telemetry, Command and Control Antenna System

Frequency	Telemetry frequency	Command and control frequency	Frequency	Telemetry frequency	Command and control frequency
Gain fluctuation in the equatorial plane (dB)	<3	<3	Isolation between the command and control antenna and the telemetry antenna (dB)	>58	
Gain within the +/-30° range in the meridian plane (dB)	> -3	> -3	Isolation between the telemetry antenna and the communications antenna (dB)	>51	
Feed cable loss (dB)	2.23	1.8	Form of polarization	LHCP	RHCP

Three antenna systems with this design have been built and installed on three Chinese communications satellites launched in February 1986, March 1988 and December 1988, respectively. At the present time, all three antenna systems are still operational on orbit, providing domestic communications service and transponding the three television programs of the Central Television Station. On-orbit test results from the Shijiazhuang ground station show that the EIRP varies from 34.4-36.6 dBW, depending on the output power of the transponder (8W and 10W) and the feed cable loss. This proves that the on-orbit performance of the antenna is in complete agreement with ground test results.

References

1. Rudge, A. W., Milne, K., Oliver, A. D., Knight, P., "The Handbook of Antenna Design," Vol 1, Peter Peregrinus, Ltd., 1982.

2. Wei Wenyuan, Gong Deming, Chen Bisen, "Antenna Principles," Beijing: National Defense Industry Publishing House, June 1985.

3. Galindo, V., Green, K., "A Near-Isotropic Circular Polarized Antenna for Space Vehicles," IEEE TRANSACTIONS ON ANTENNA AND PROPAGATION, Vol AP-13, No 6, November 1965, pp 872-877.

4. Simmons, Alan J., "A Compact Broad-Band Microwave Quarter-Wave Plate," PROCEEDINGS OF THE I.R.E., Vol 40, No 9, 1952, pp 1089-1090.

END OF
FICHE
DATE FILMED

20 May 1991